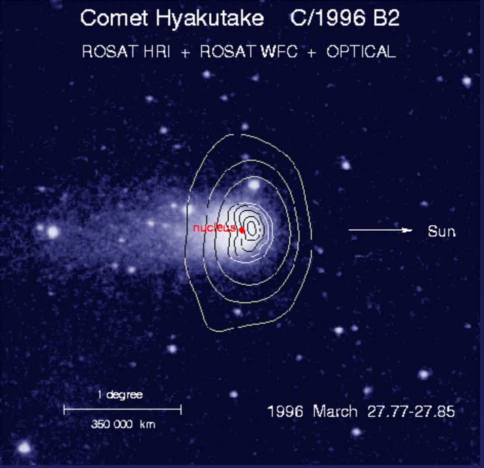
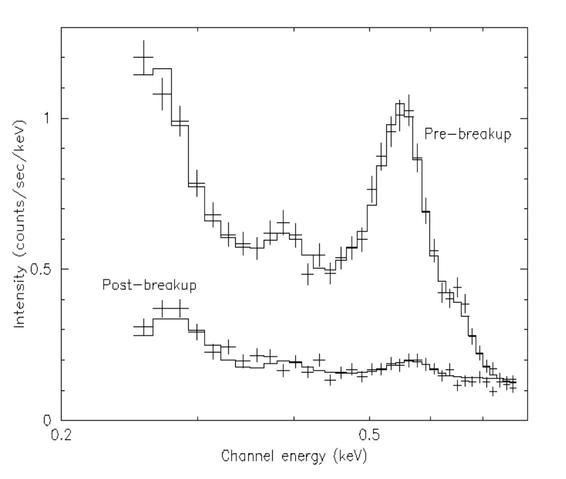
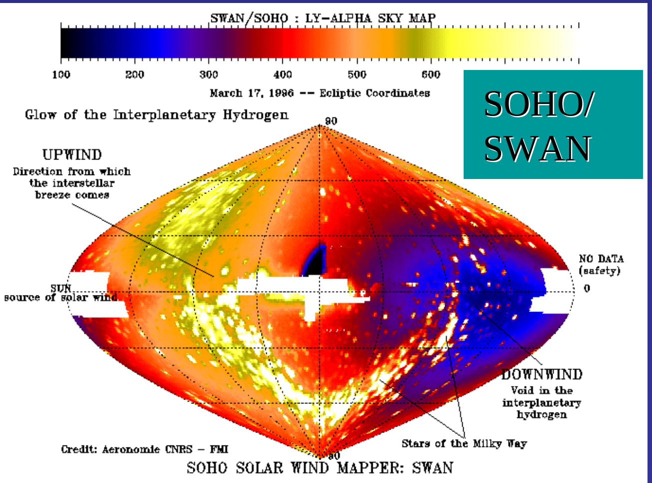


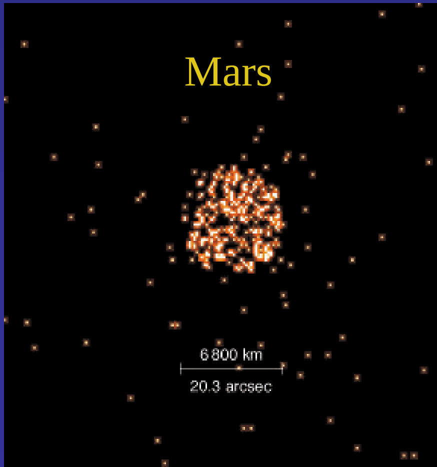


CONX & X-ray Emission from Comets, Planets & Astropsheres

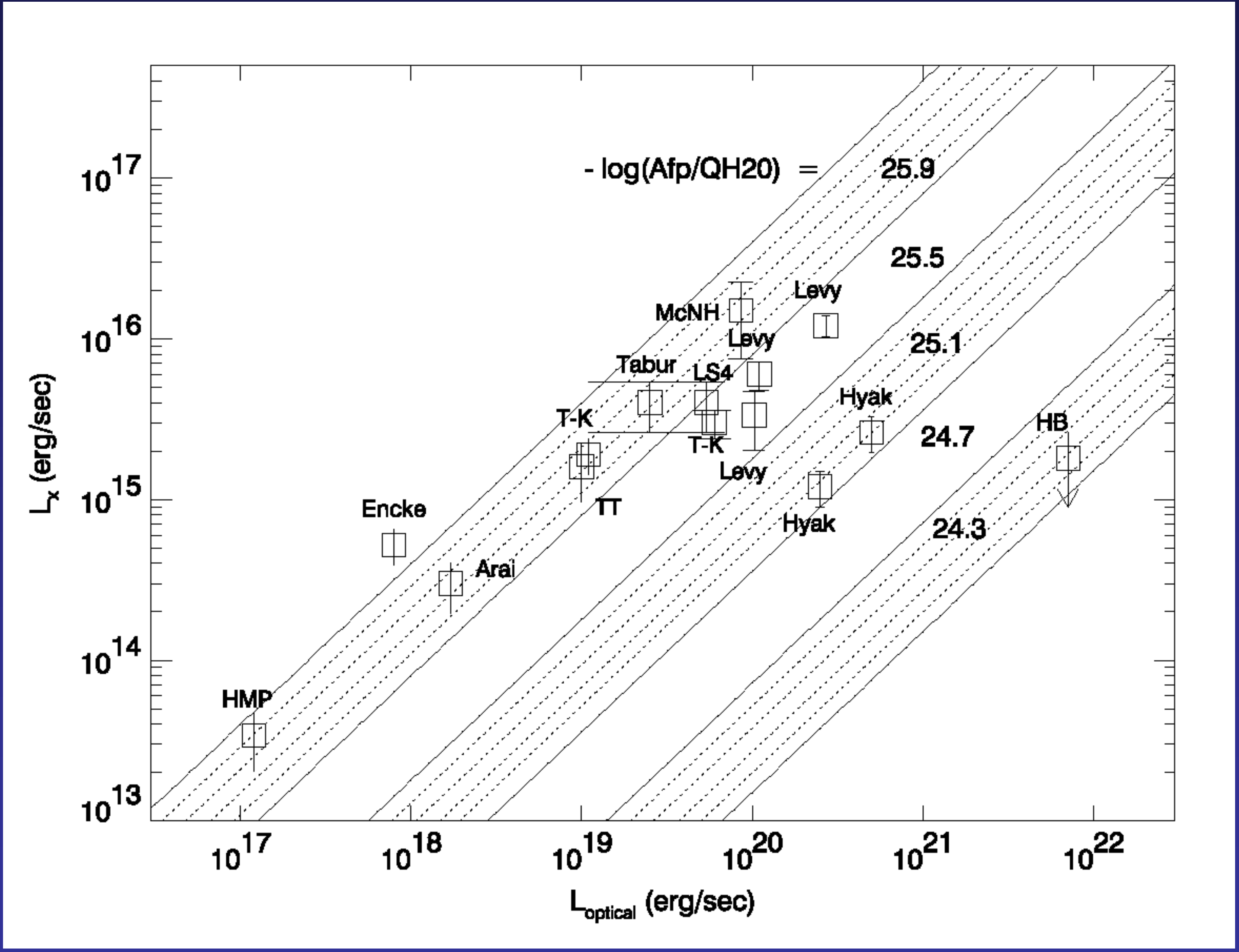
C. M. Lisse, University of Maryland



CONX FST
Greenbelt, MD, USA
November 19, 2003



X-ray Emission : A Property of All Comets

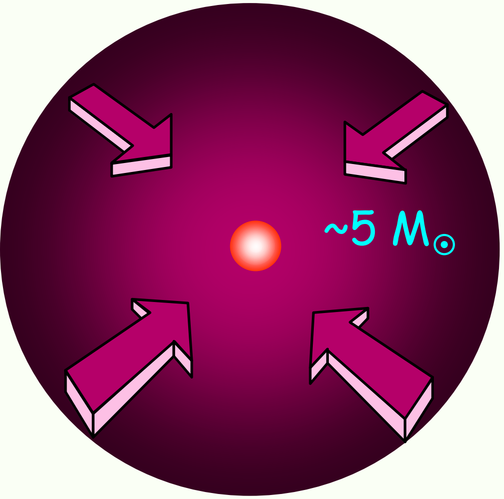


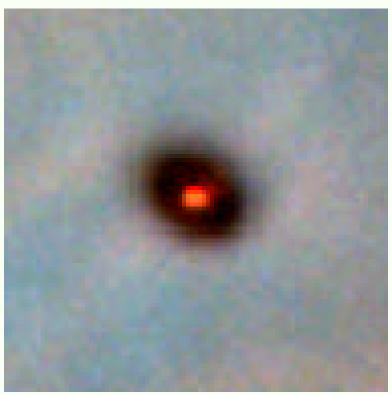
- $L_x \sim L_{optical}$ at low $L_{optical}$.
- Why is there an apparent asymptote at high $L_{optical}$, $L_x \sim 10^{16}$ erg/sec ???

Planetary System Formation

Protostar

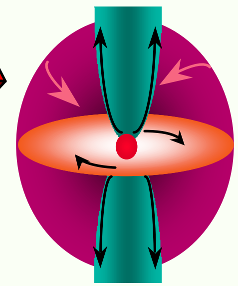
$T < 10^4$ yr





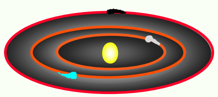
Disk & Jet

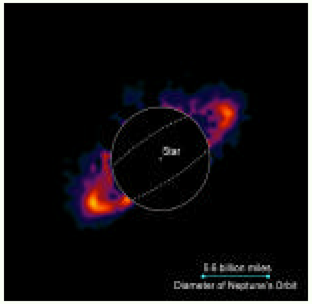
~10^5 yr

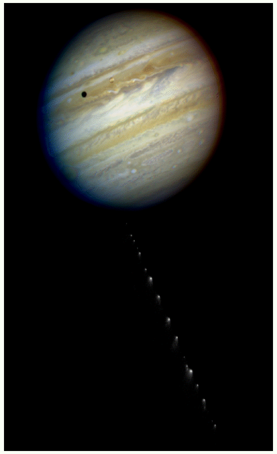


Planetisimals,
Proto-planets,
Dusty Disks

~10^7 yr

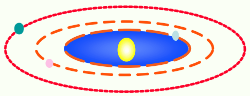


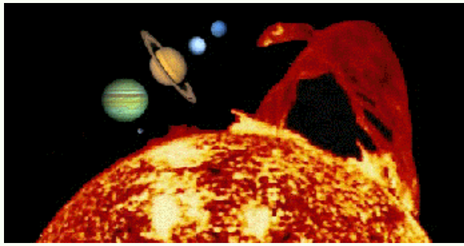




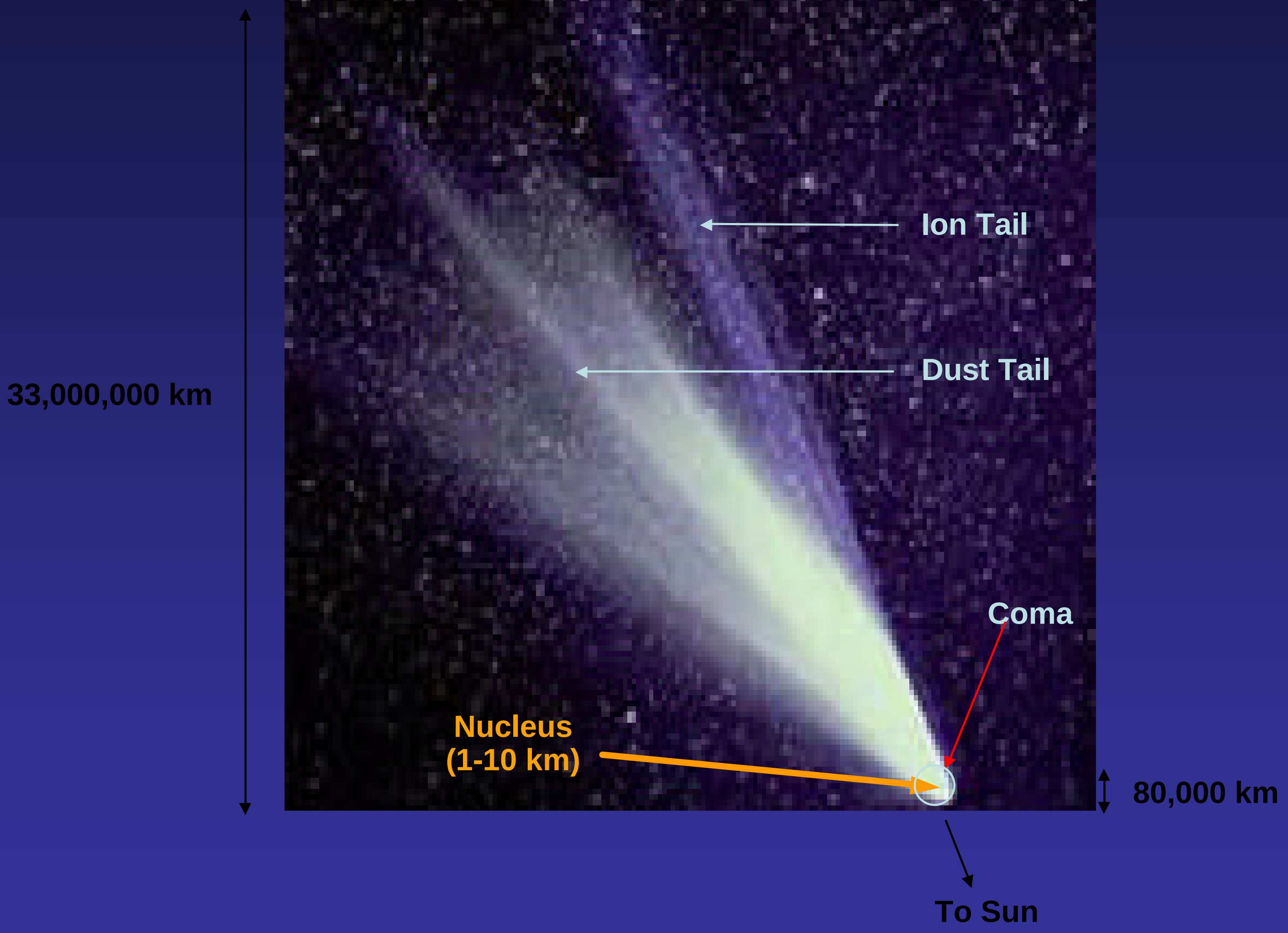
Planetary system

$T > 10^8$ yr





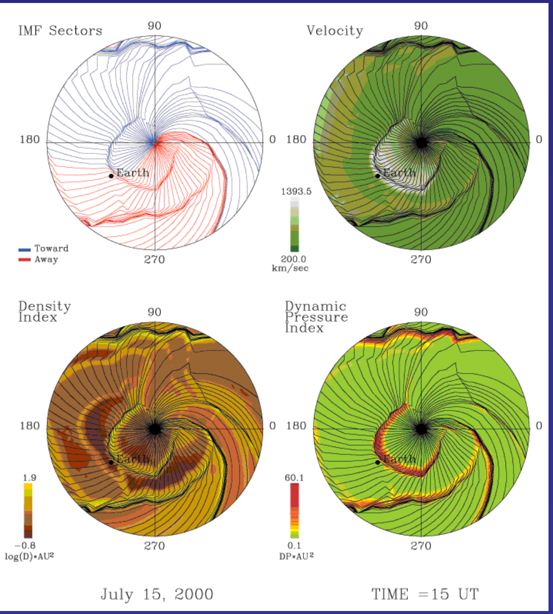
Anatomy of a Comet

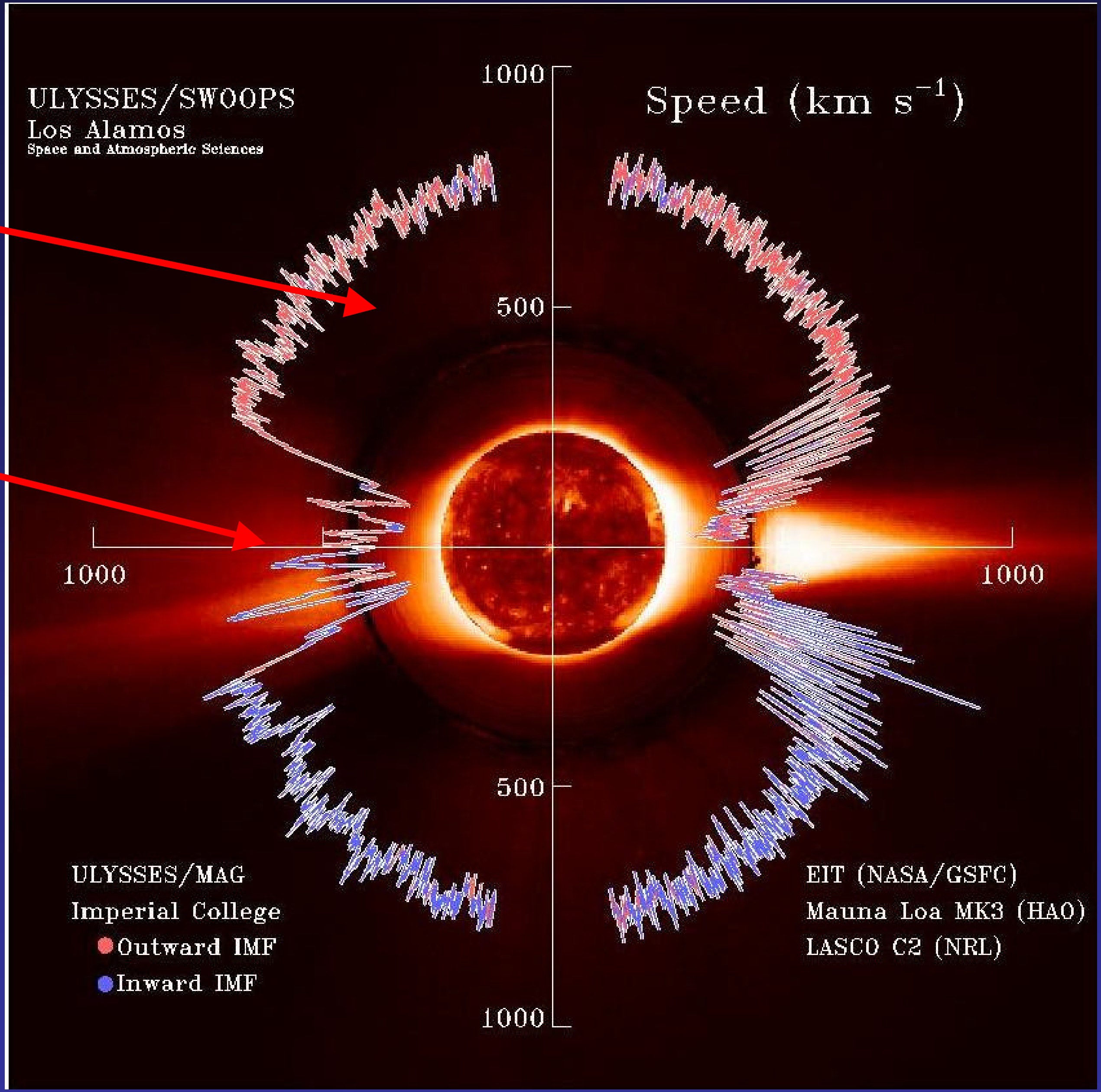


Or with the varying solar wind?

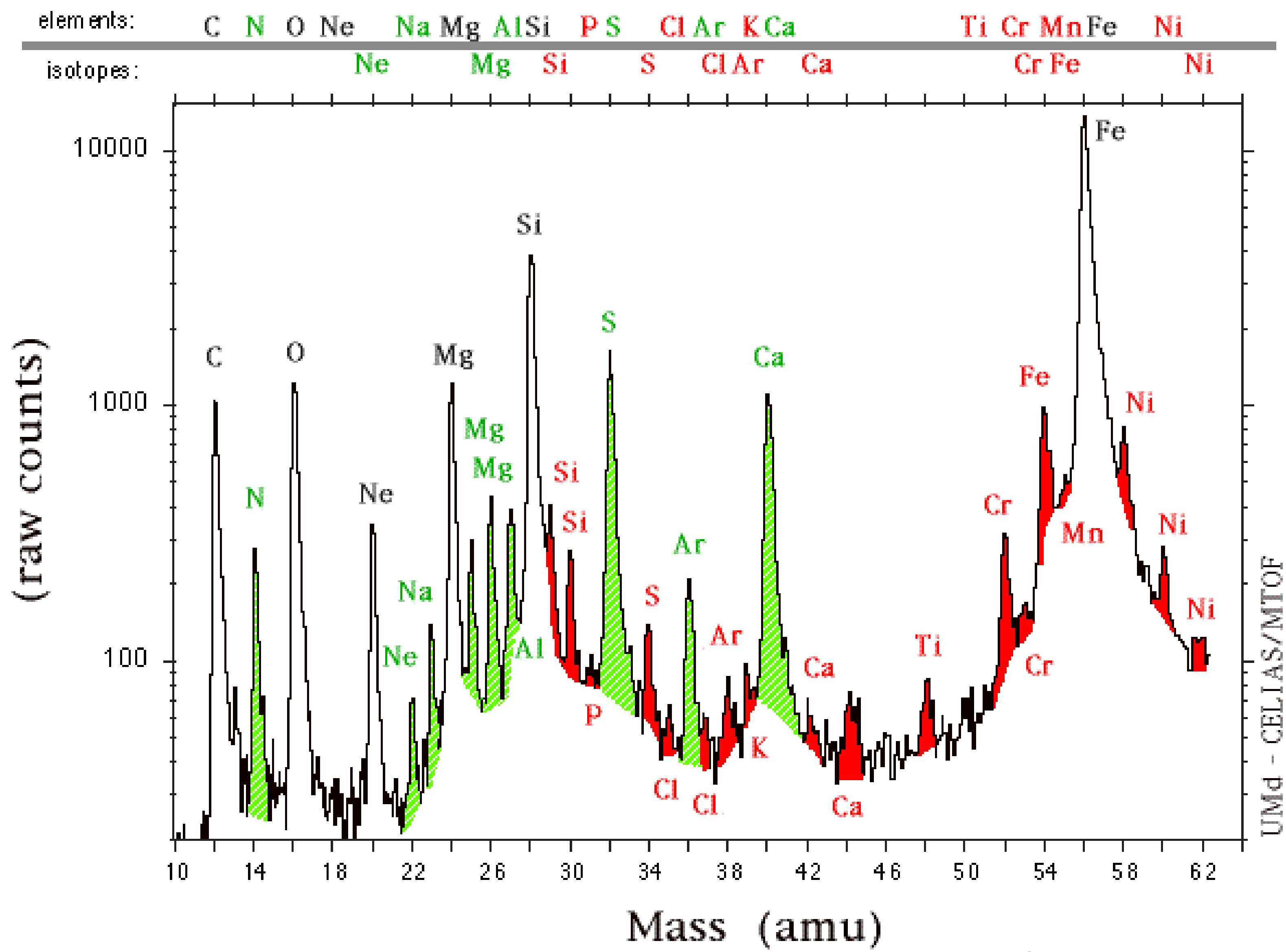
Fast Solar Wind

Slow Solar Wind

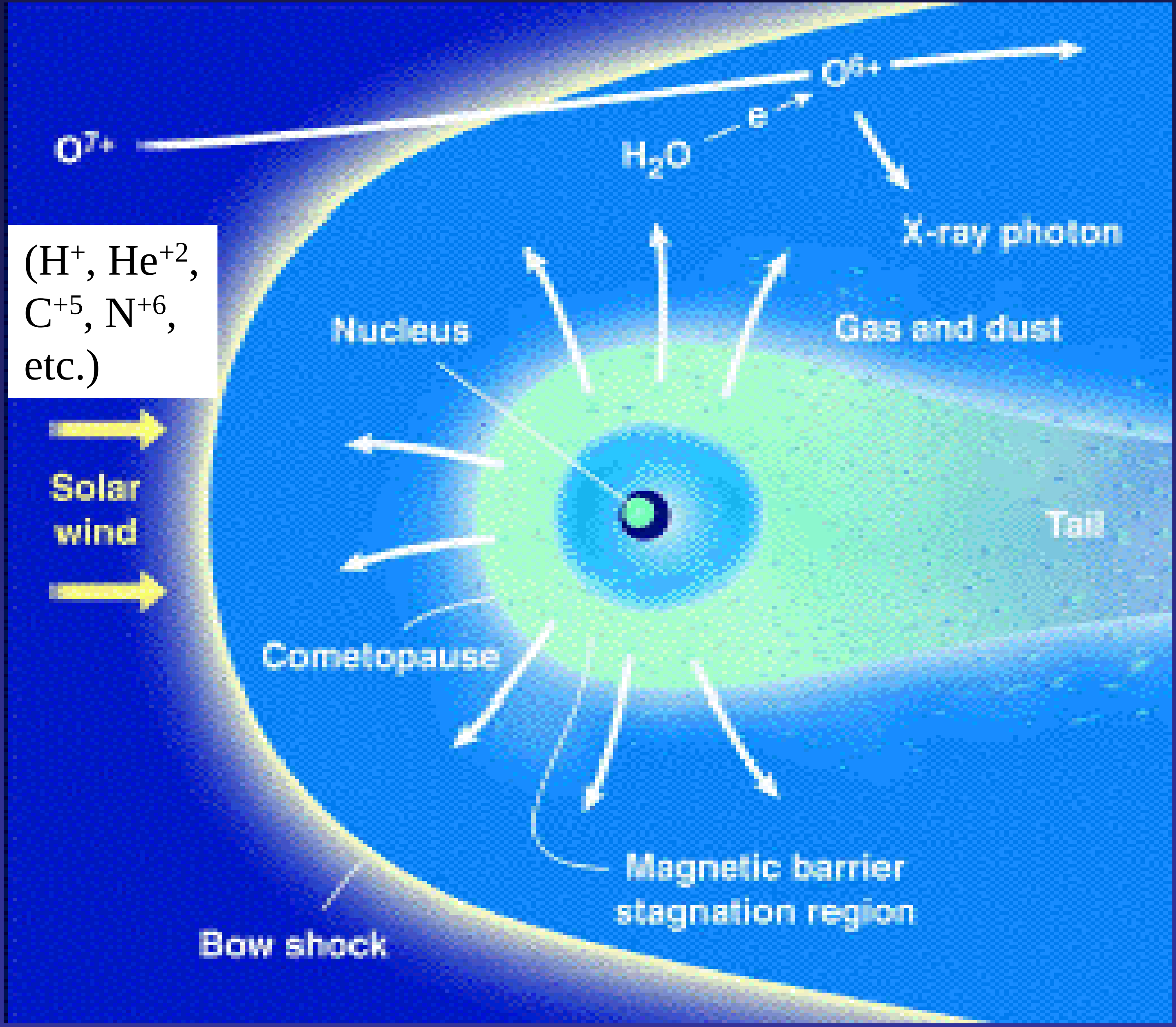




Solar Wind Elements/Isotopes Observed by SOHO/CELIAS

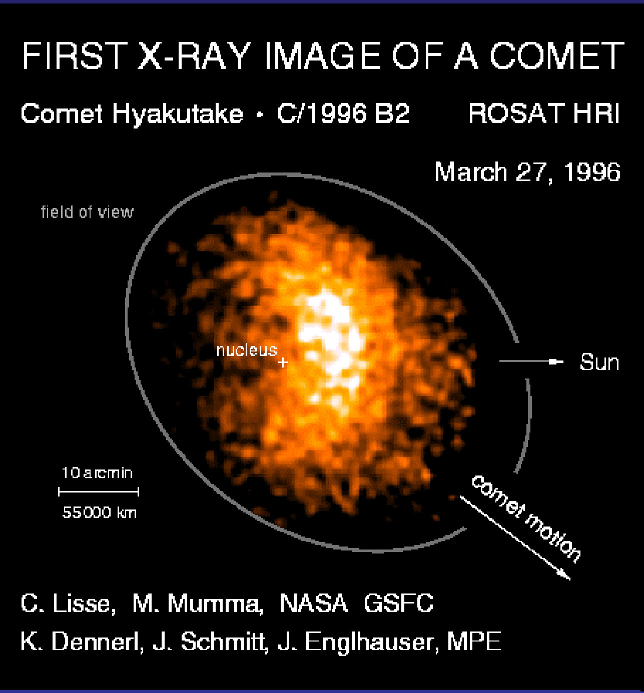


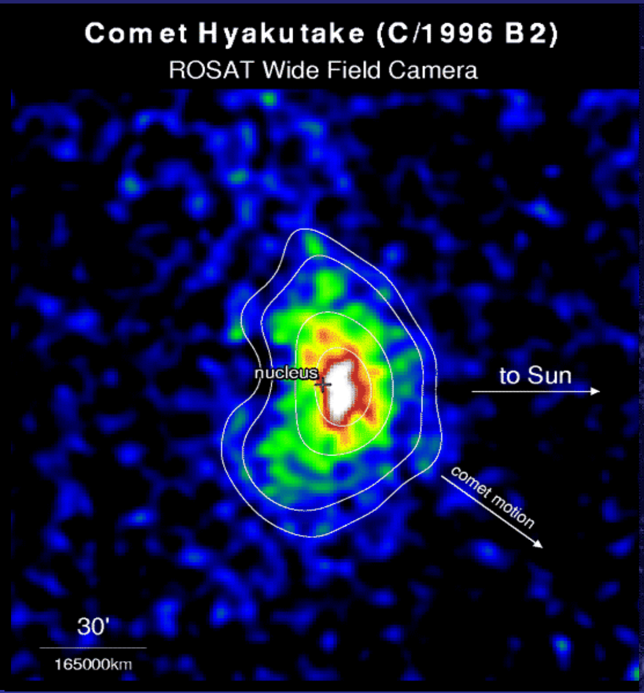
Solar Wind Encountering a Comet + CXE

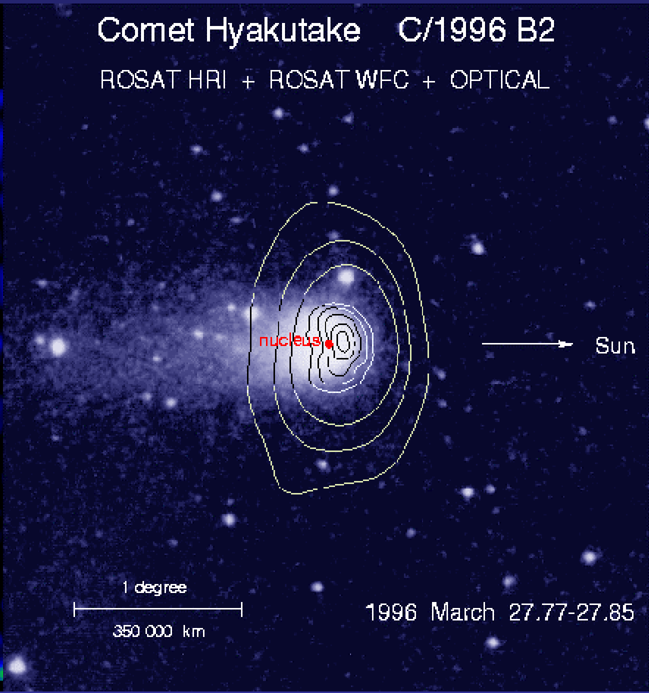


Observable #1 -Morphology
C/1996 B2 Hyakutake Discovery Images

- Similar morphology in X-ray/EUVE
- Symmetry Around the Sun-Nucleus Line
- No Correlation with Comet’s Motion - no Ibadov emission

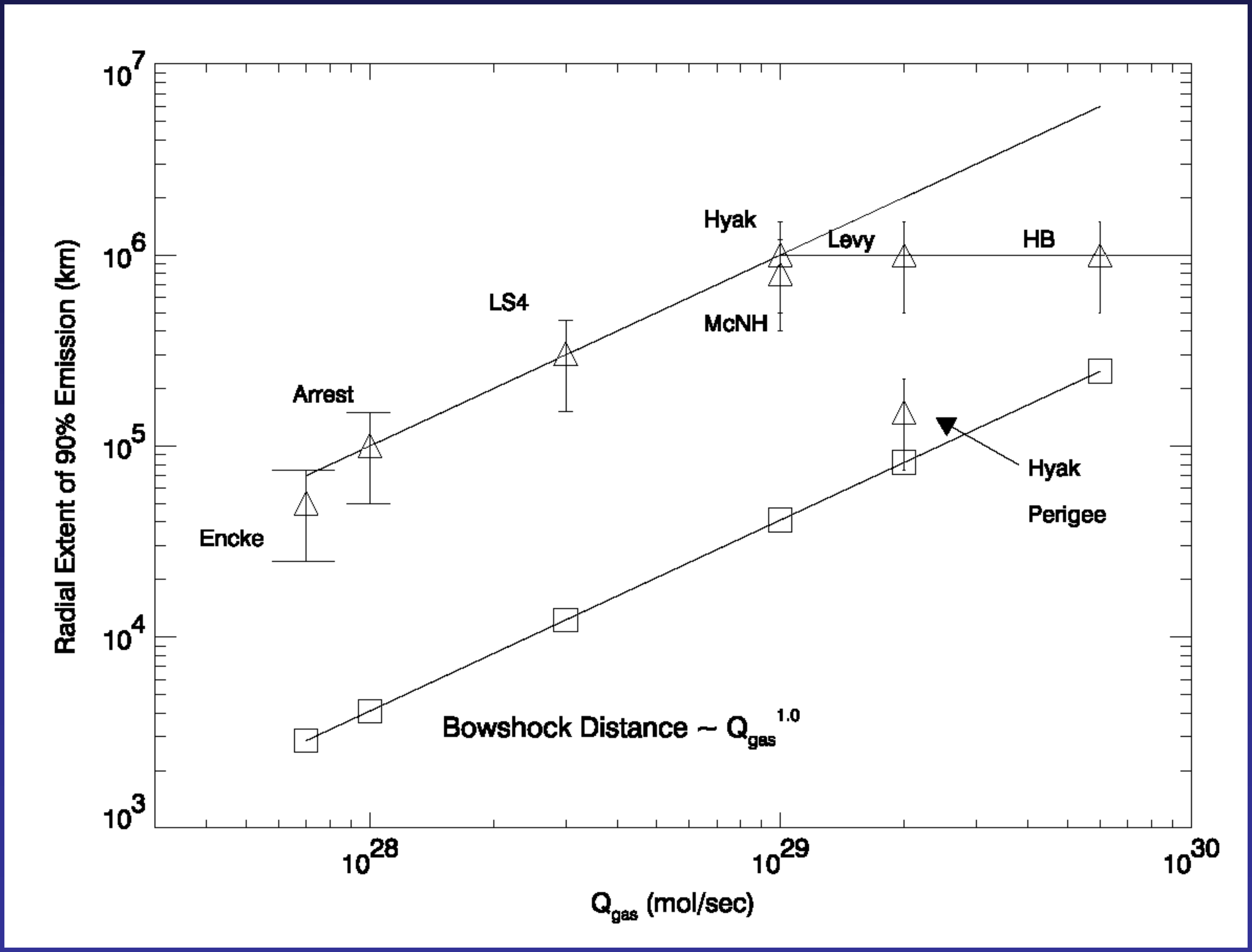






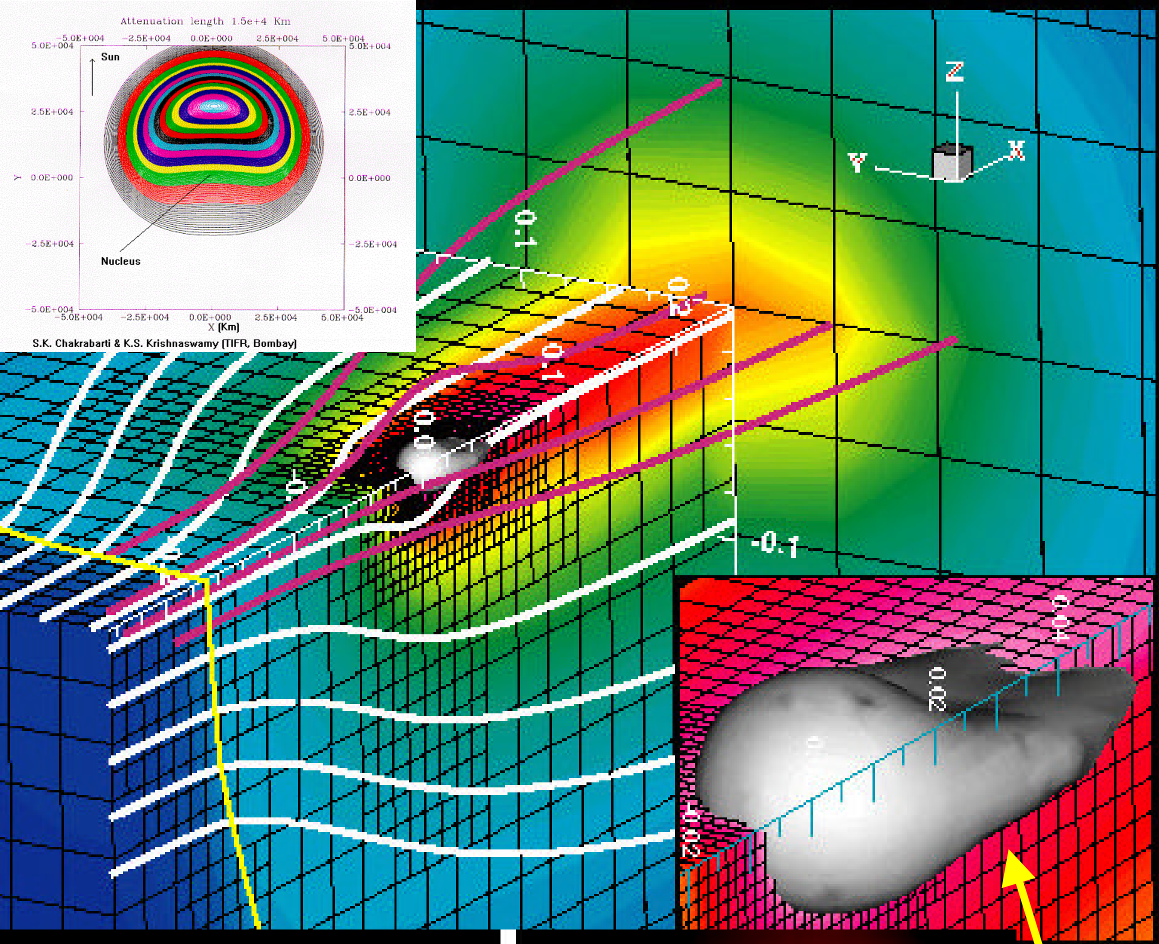
(Lisse et al. 1996)

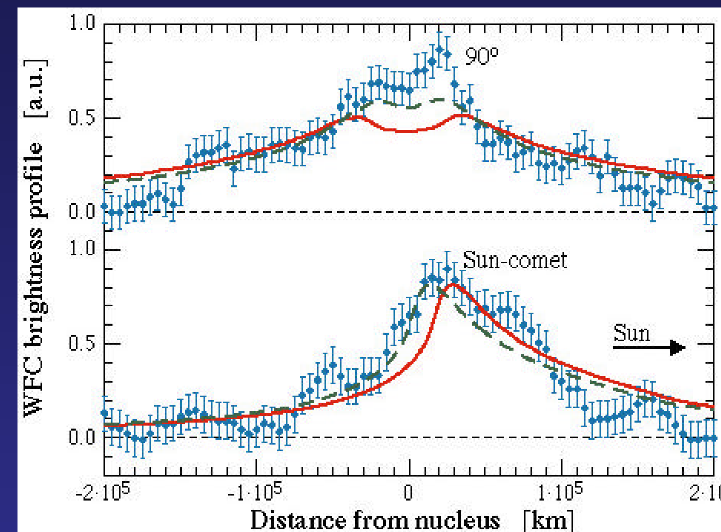
X-ray Radial Extent vs Comet Outgassing Rate (Q_{gas})

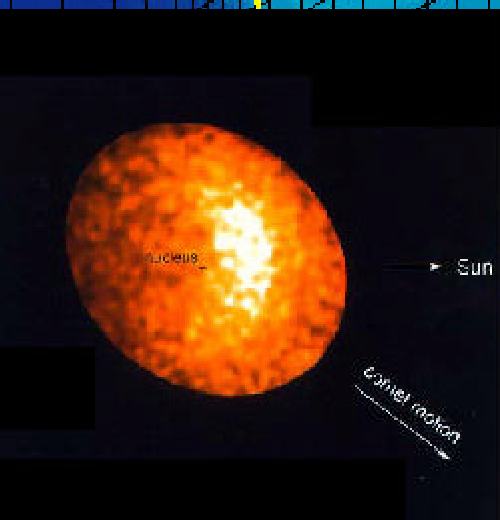


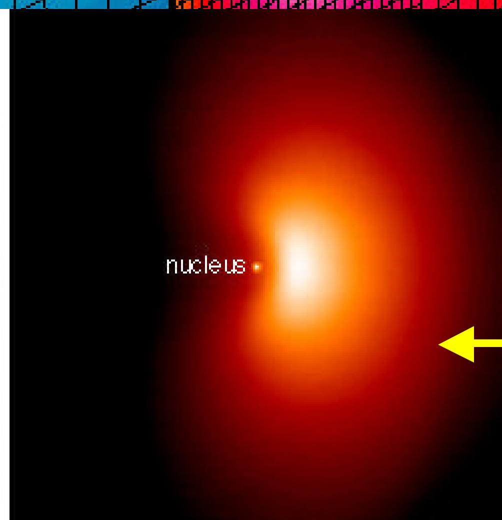
- Radial Extent ~ $Q_{gas}^{0.75}$
- Asymptote at large Q_{gas}?
- No correlation w/ bowshock position => not mag field, or shock driven

Emission Region Models

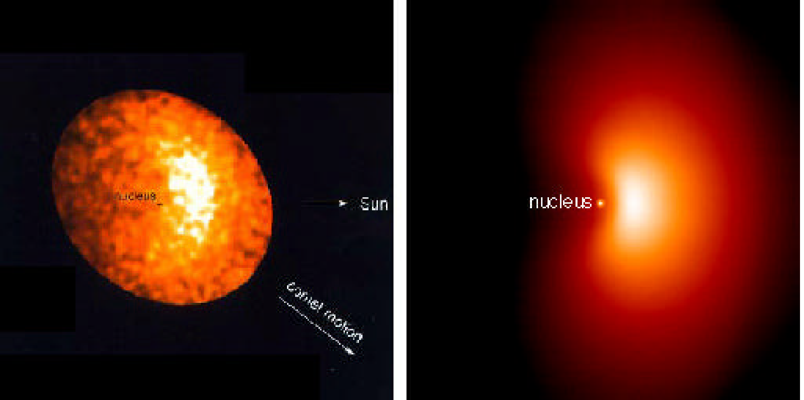






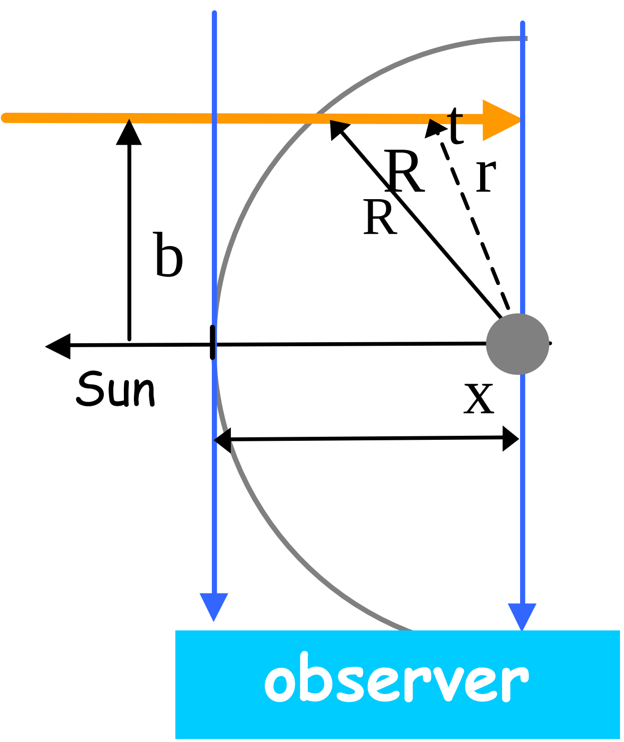


Current models range from sophisticated 3-D MHD (Haeberli et al. 1997, Wegmann et al. 1998) to simple 2-D collisionally thick w/o physics (Krishna-Swamy 1997)

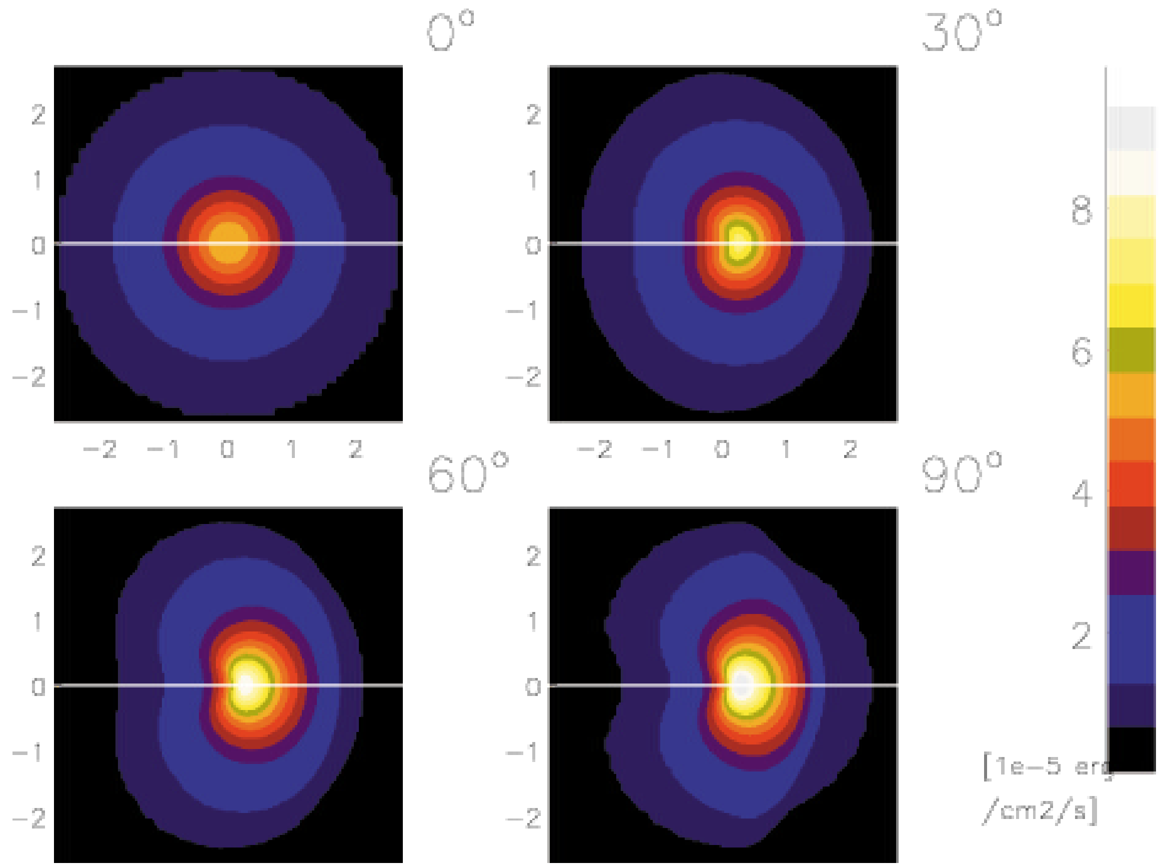


Hyakutake at 90º phase

Future Work w/ CONX- Understanding the CXE Interaction Cross Section Using the Morphological Variation with Phase Angle

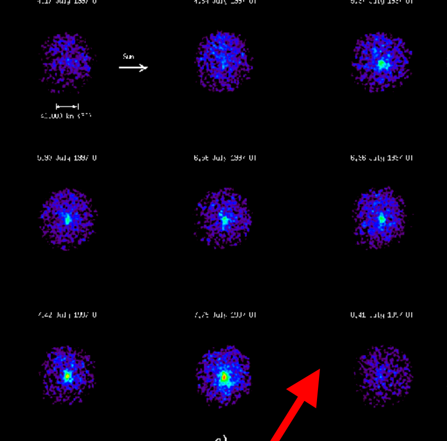


X-ray images are 2-D projection of a 3-D hemispherical shell

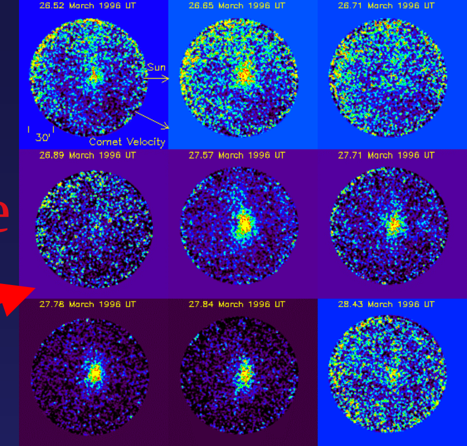


R. Wegmann (2003)

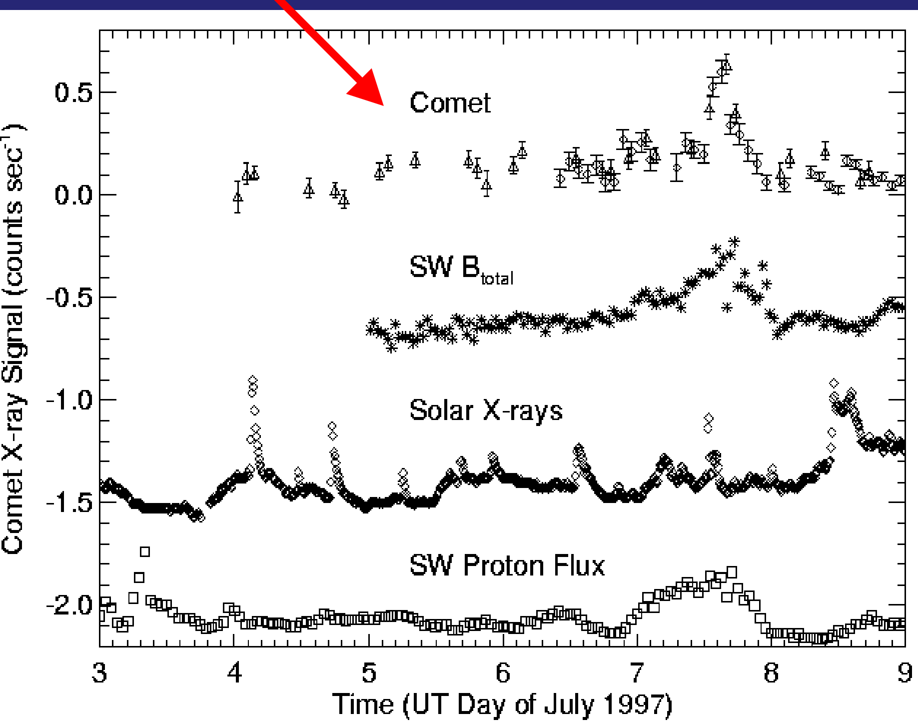
Observable #2 : Light Curves

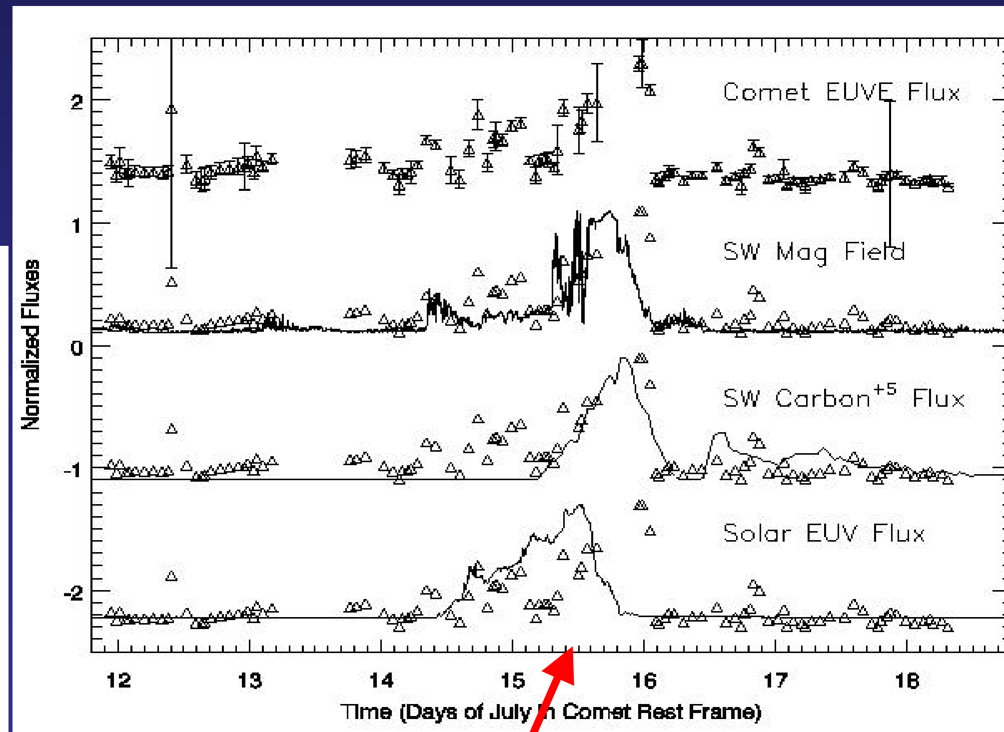


Encke July 1997 w/ Full Carrington Shift



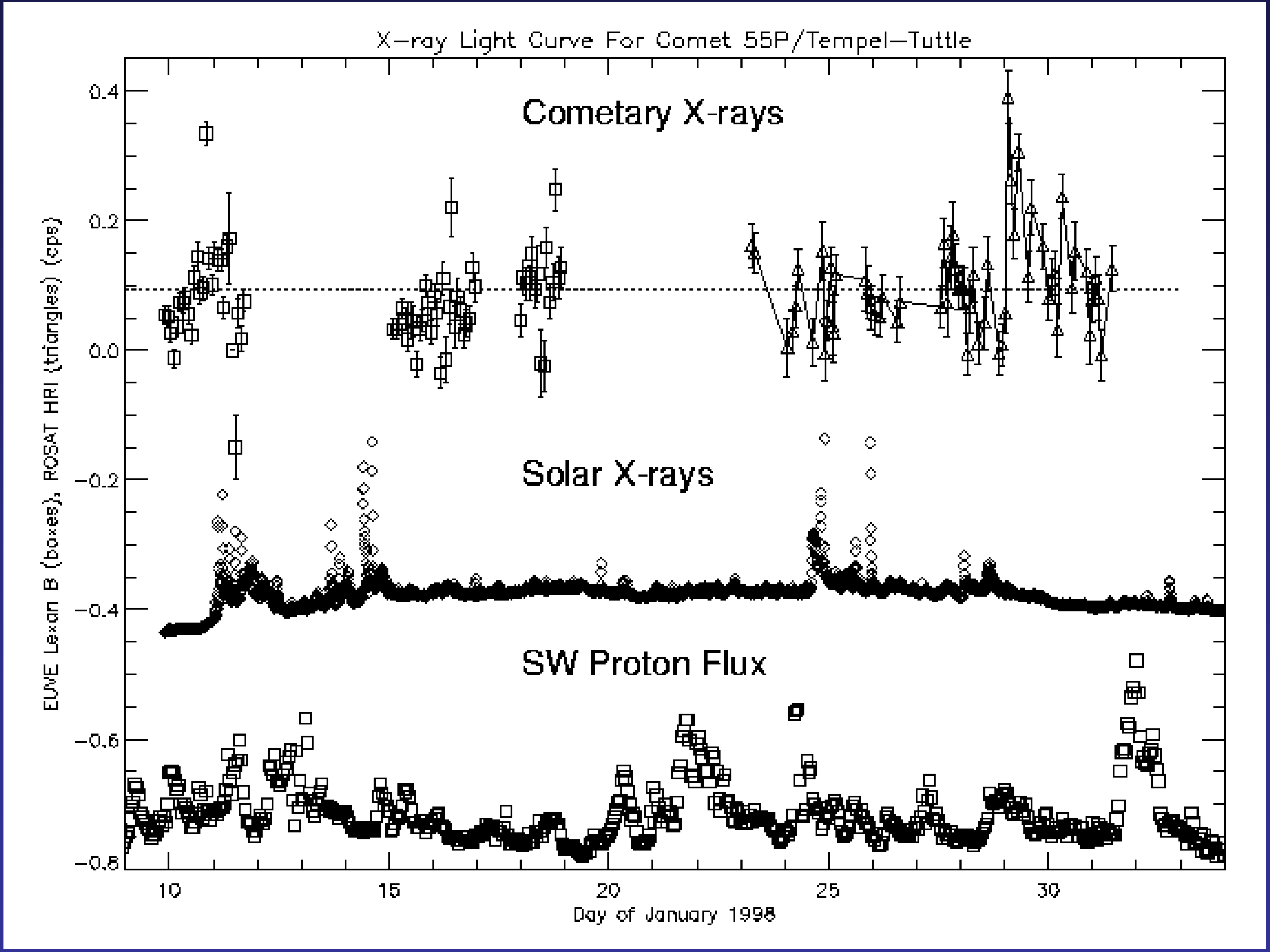
Hyakutake March 1996





LINEAR 1999 S4 July 2000 Mag Field radial shift ONLY

Luminosity : Light Curves II



Tempel-Tuttle January 1998

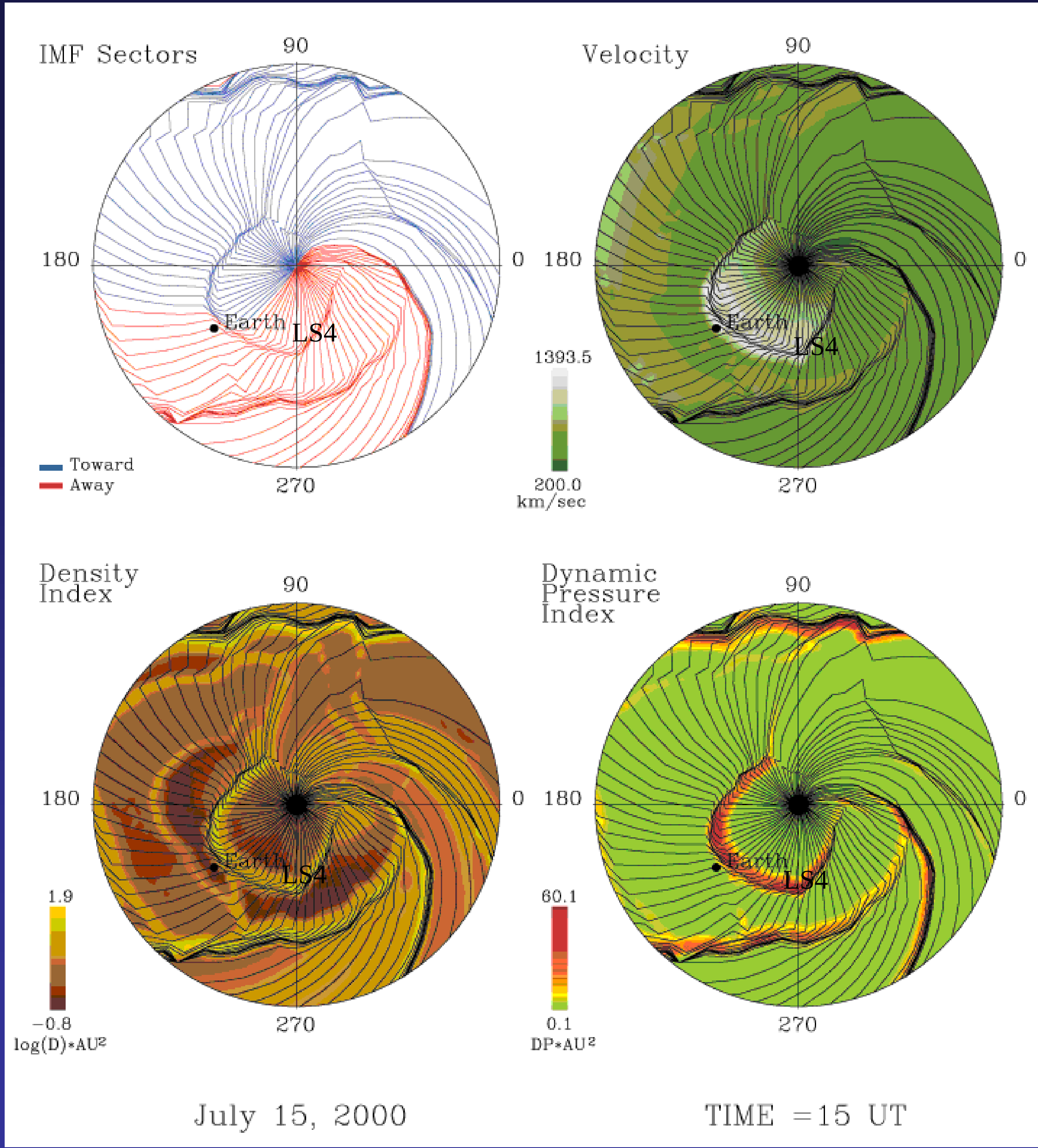
Predicted and Observed Light Curve Phase Shifts Using the Latitude Independent Model

Comet	Time of Impulse (00:00H UT)	Δt_{long} (days)	Δt_{radial} (days)	Δt_{Total} (days)	$\Delta t_{observed}$ (days)
Hyakutake	27 Mar 1996	-0.23	0.032	-0.20	-0.24
Hale-Bopp	11 Sep 1996	-4.60	5.9	1.30	+1.4
Encke	7 Jul 1997	-0.26	0.093	-0.17	-0.1
Tempel-Tuttle	29 Jan 1998	-2.31	0.37	-1.94	-2.5
LINEAR S4	15 Jul 2000	+1.2	-0.4	+0.8	-0.4 (!!)

N.B. : time shifts assume solar wind velocity as measured near-Earth; positive time shifts = impulse happens at Earth first, comet next; negative time shifts => boundary hits comet first, Earth next.

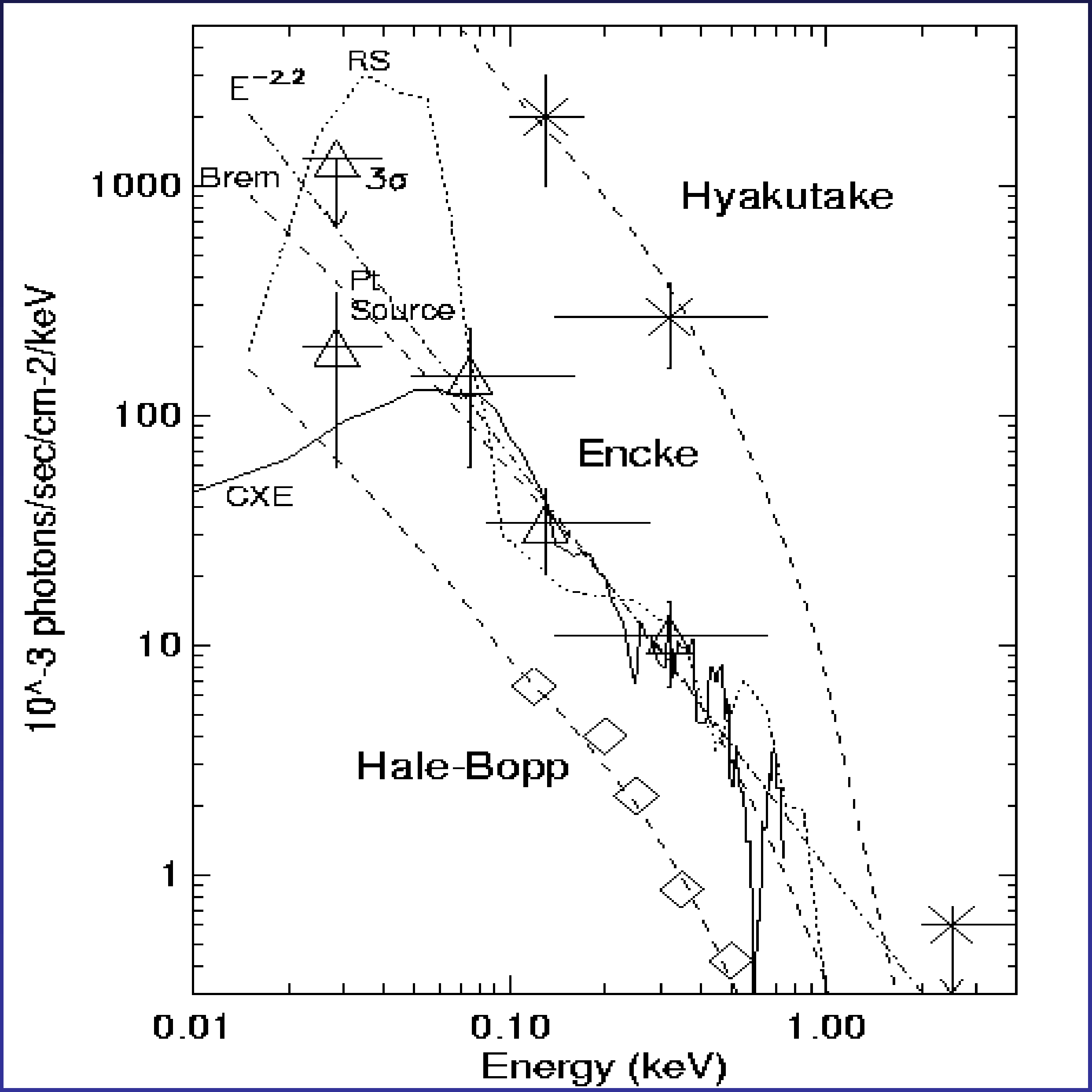
Space Weather Detection : the 2000 Bastille Day Event & LINEAR S4

The CME was broadcast into a 90º region heading radially from the Sun towards the Earth and C/1999 S4 (LINEAR).



M. Dryer et al., Solar Physics 204: 267-286, 2001

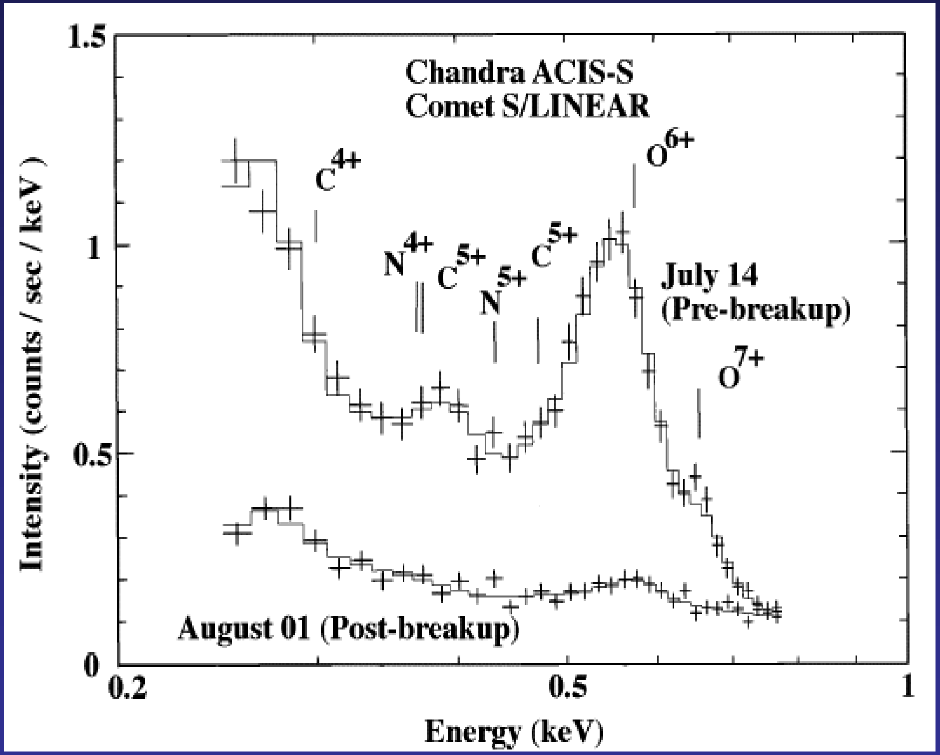
Observable # 3 - Photometry/Spectroscopy

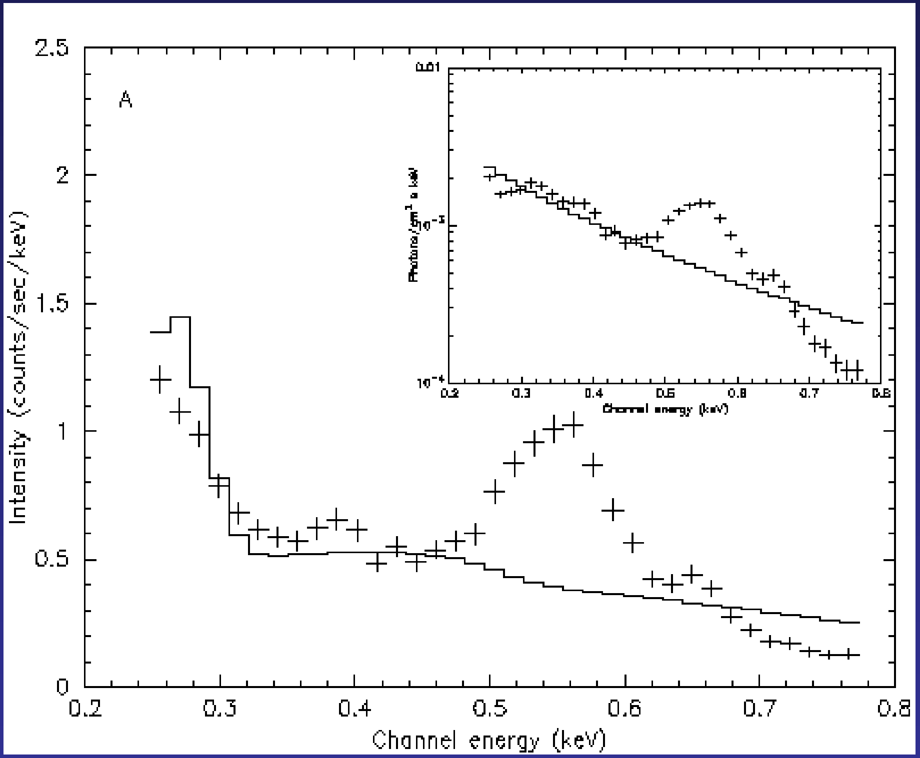


- Good fit with CXE, Power Law, Bremstrahhlung
- Most photons emitted between 1 - 200 eV

Chandra/XMM Era : Spectroscopy

C/1999 LINEAR S4 (Lisse et al. 2001) : 1st Good X-ray Spectrum



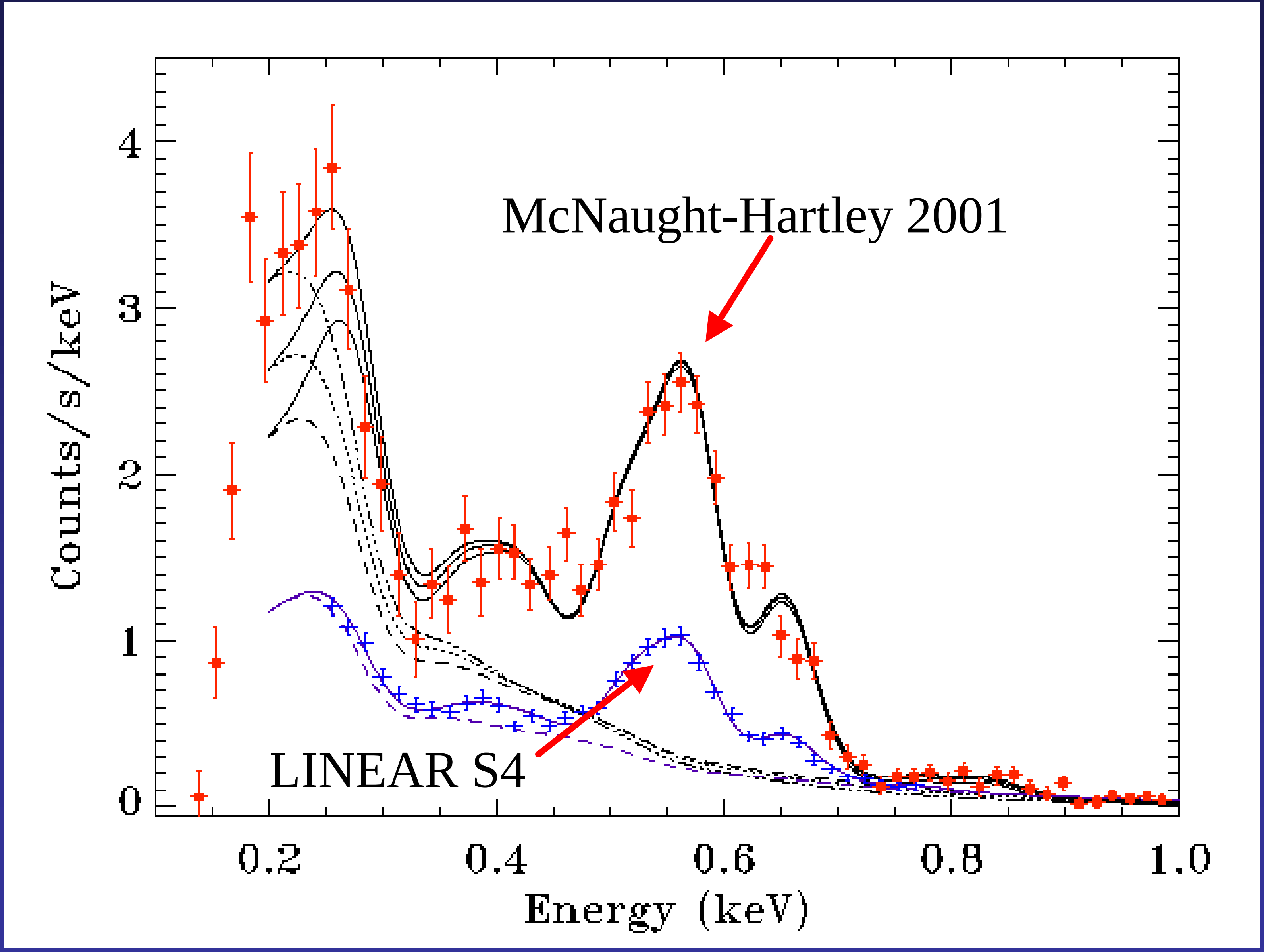


Chandra ACIS-S Medium Resolution Spectrum

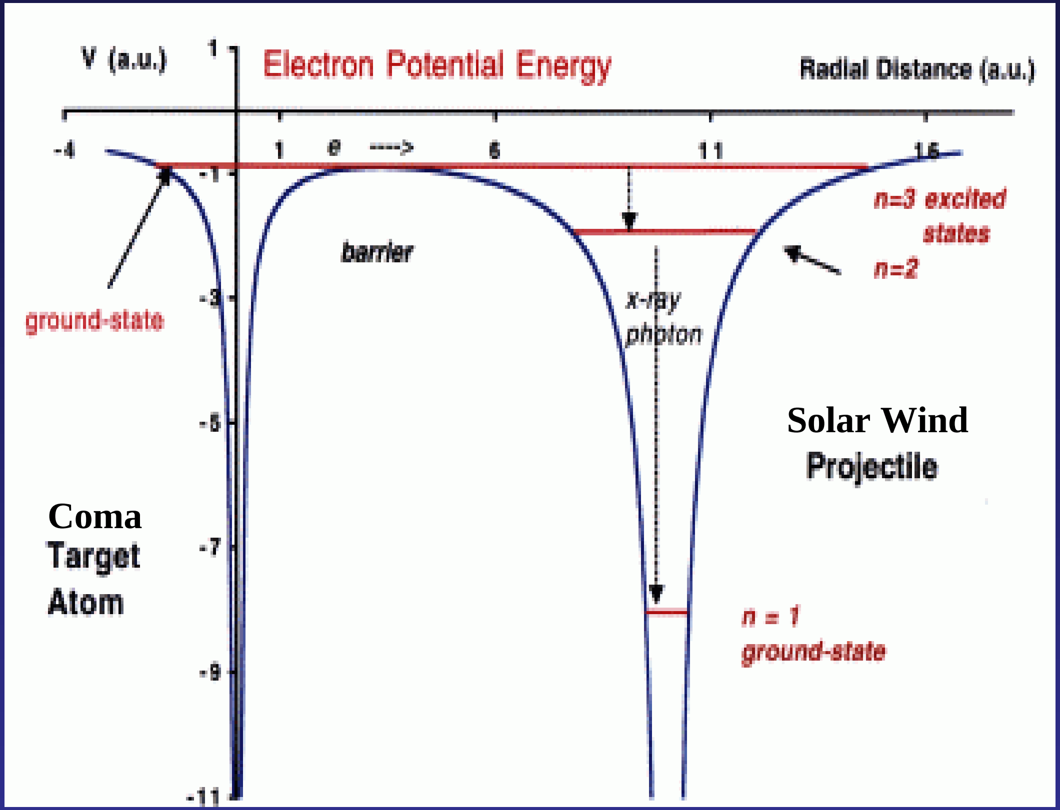
Definitely Not Pure Bremsstrahlung Emission

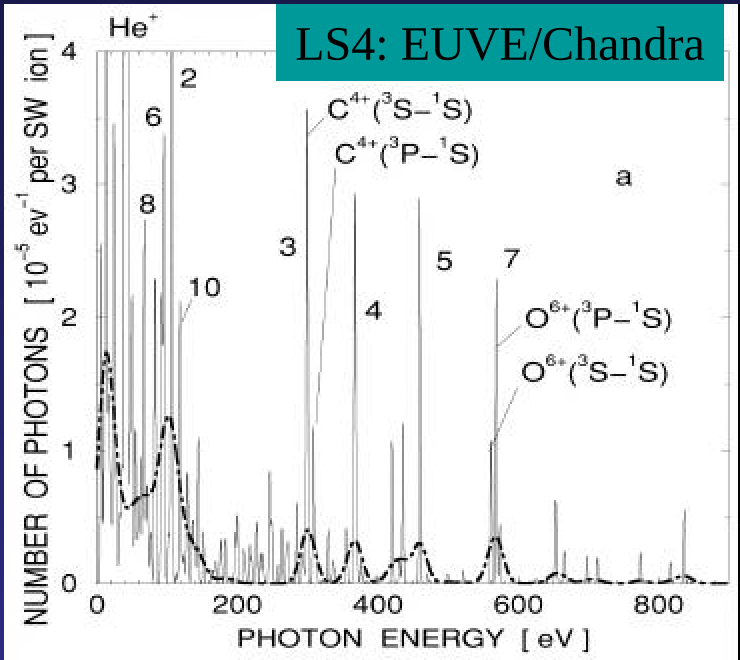
Confirmation of the Chandra Emission Spectrum :

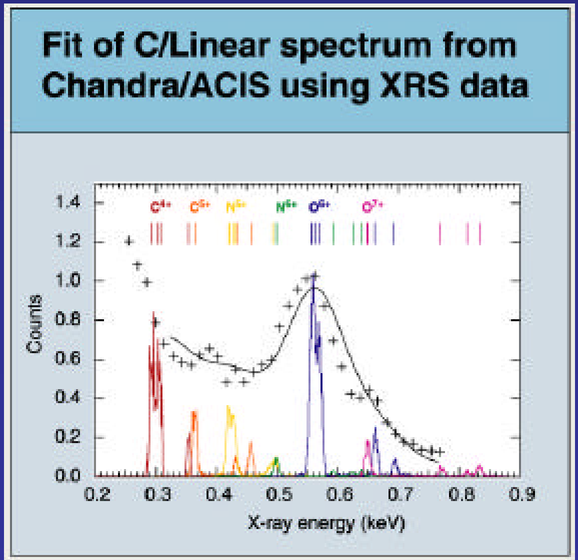
C/McNaught-Hartley 2000 T1 (Krasnopolsky et al. 2002)



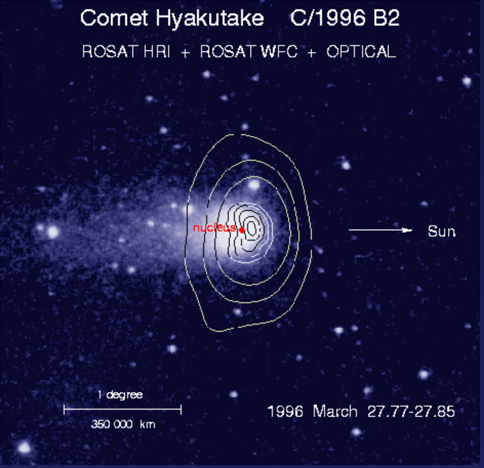
Spectral Modeling & Lab Measurements of Cometary CXE

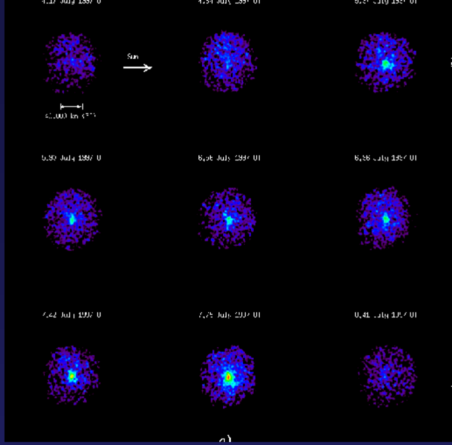




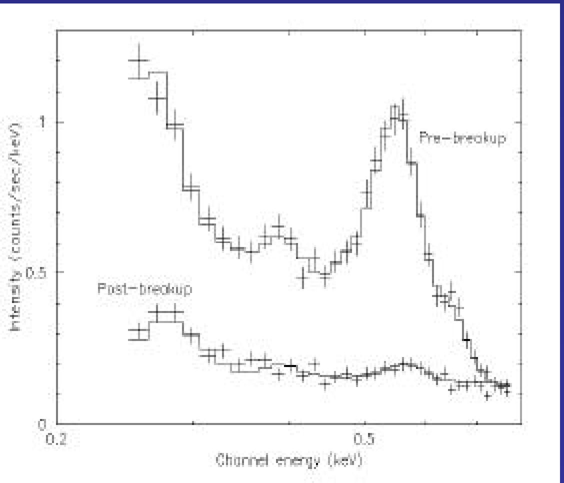


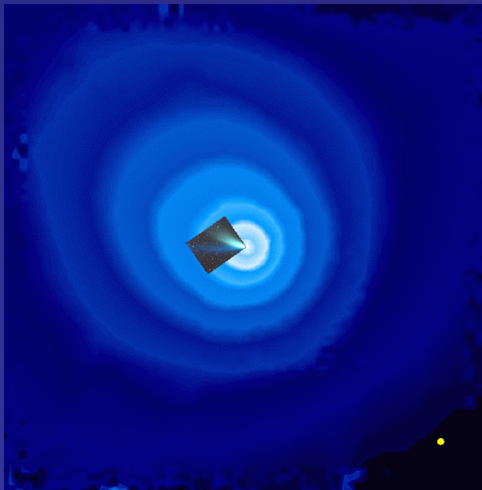
- OVII/OVII line ratios variable
- He^+,background signal huge at E < 250 eV
- All lines, or lines + continuum?
- Fast vs slow solar wind - expect different spectra
- Auger e^- quenching on dust, surfaces (Hale-Bopp)?
- Role of Collisions in the cometary atmosphere?





What CONX Can Do : Many Questions of Solar System and Astrophysical Import Remain…



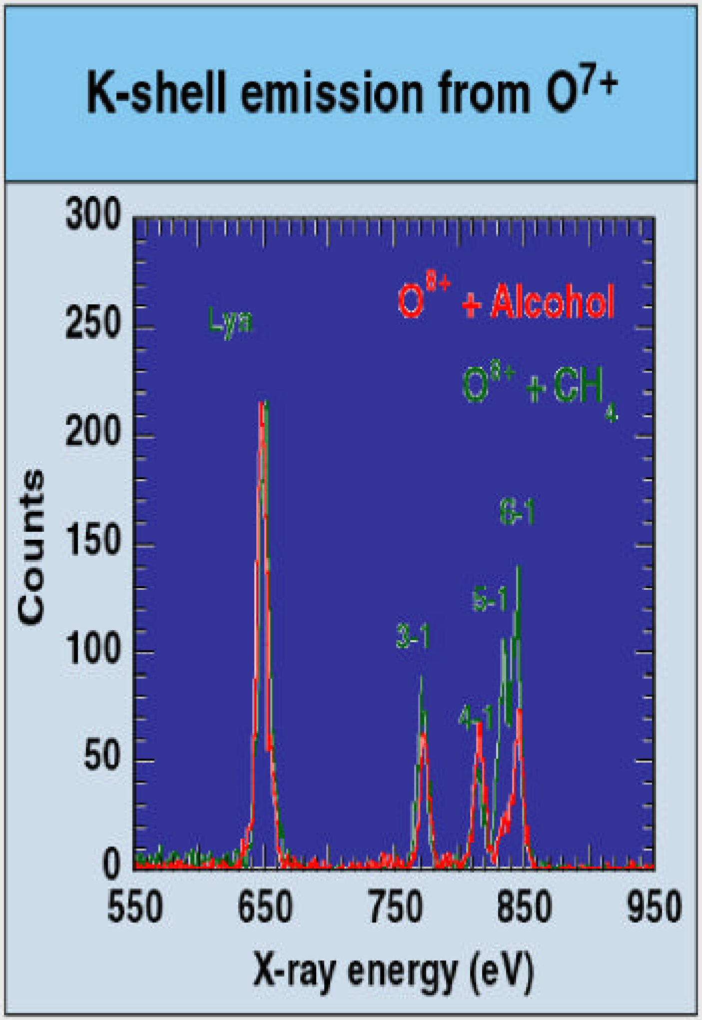


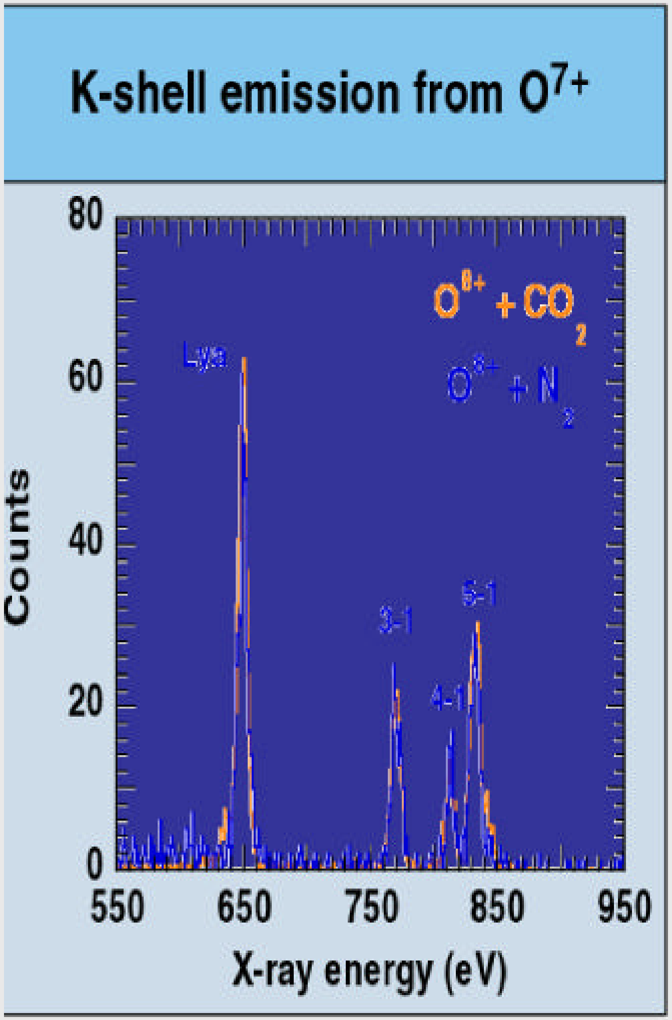
How does the x-ray emission pattern depend on the neutral comet gas?

LLNL/EBIT

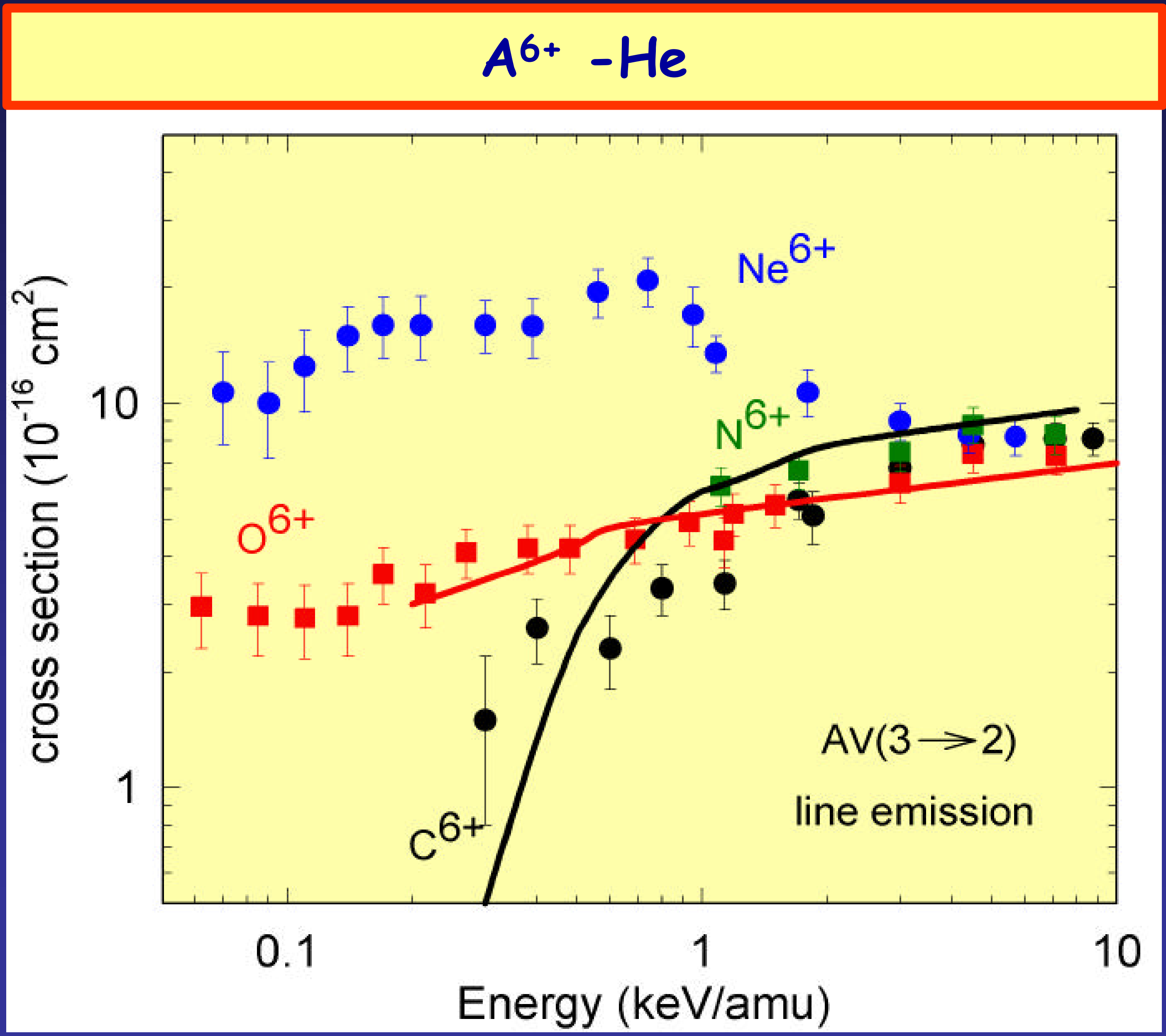
Vary the ionization potential of the interaction gas:

He:	24.59 eV
N_2:	15.58 eV
CO_2:	13.77 eV
CH_4:	12.60 eV
Alcohol:	10.49 eV





Or with the solar wind highly charged incoming ion?

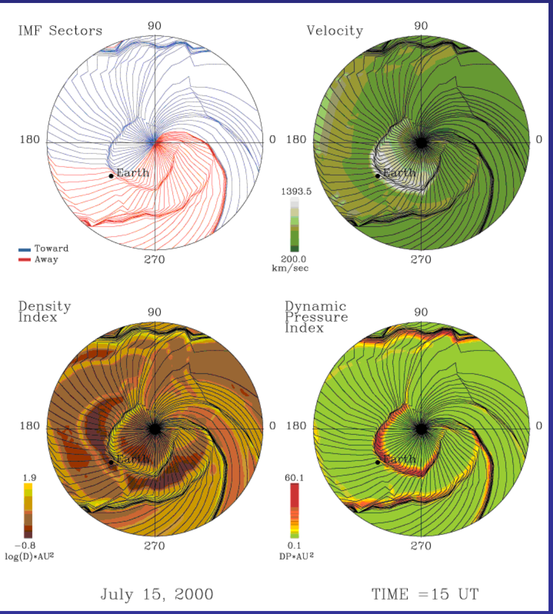


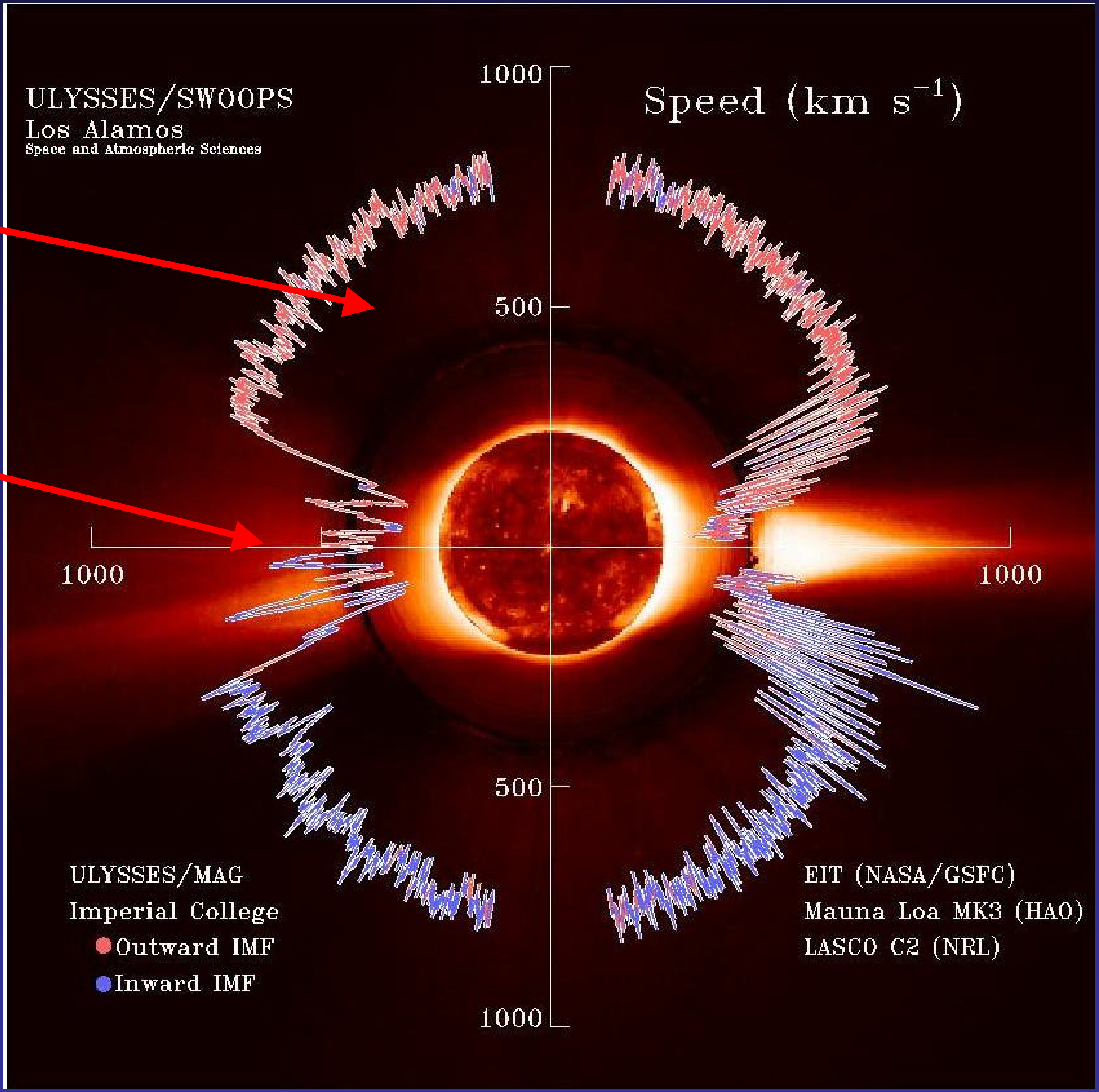
Hoekstra et al. 2003

Or with the varying solar wind?

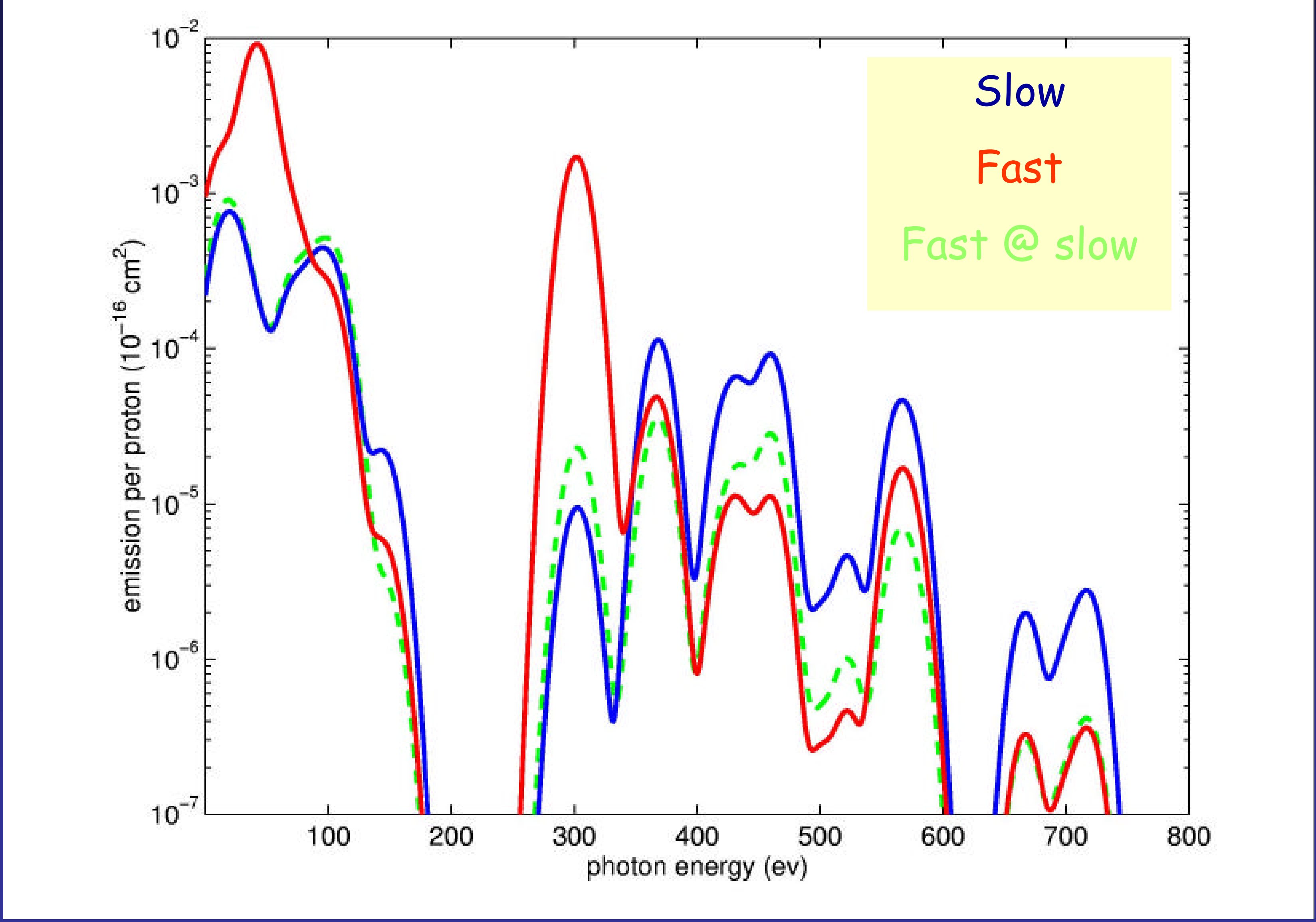
Fast Solar Wind

Slow Solar Wind





Predicted Line emission spectra

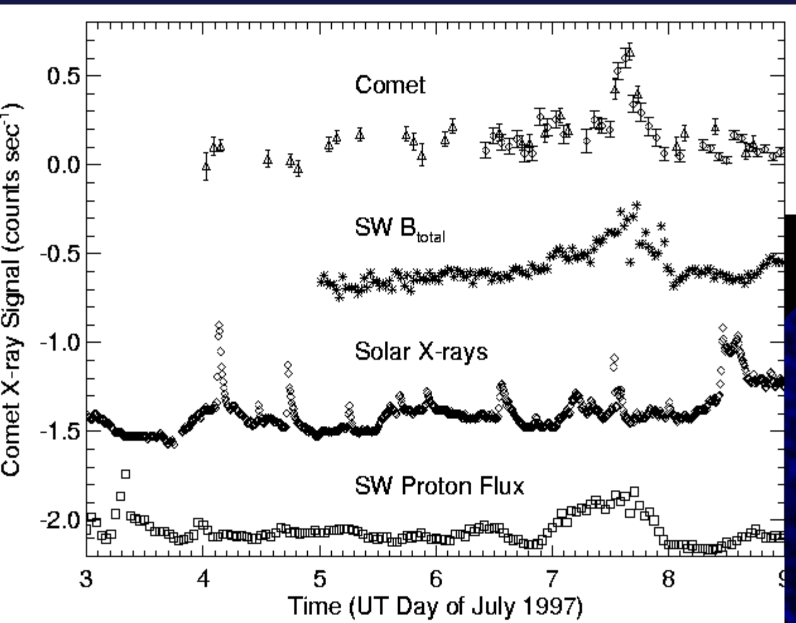


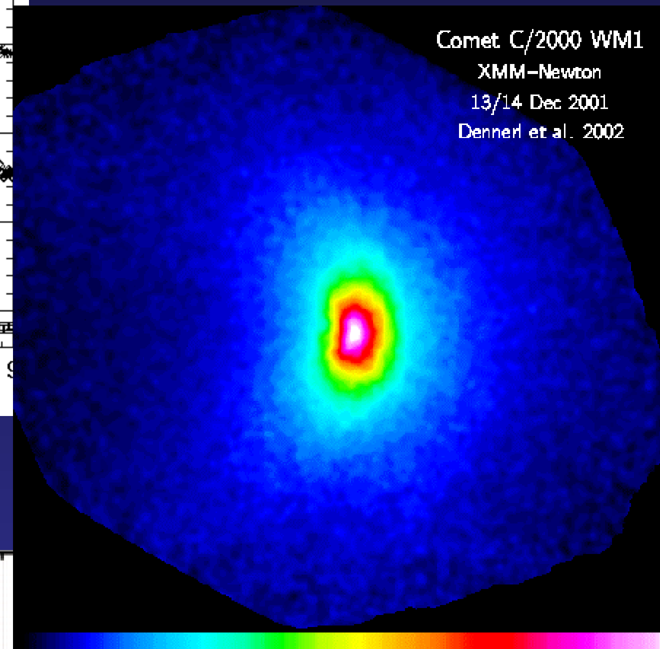
(Hoekstra et al. 2003)

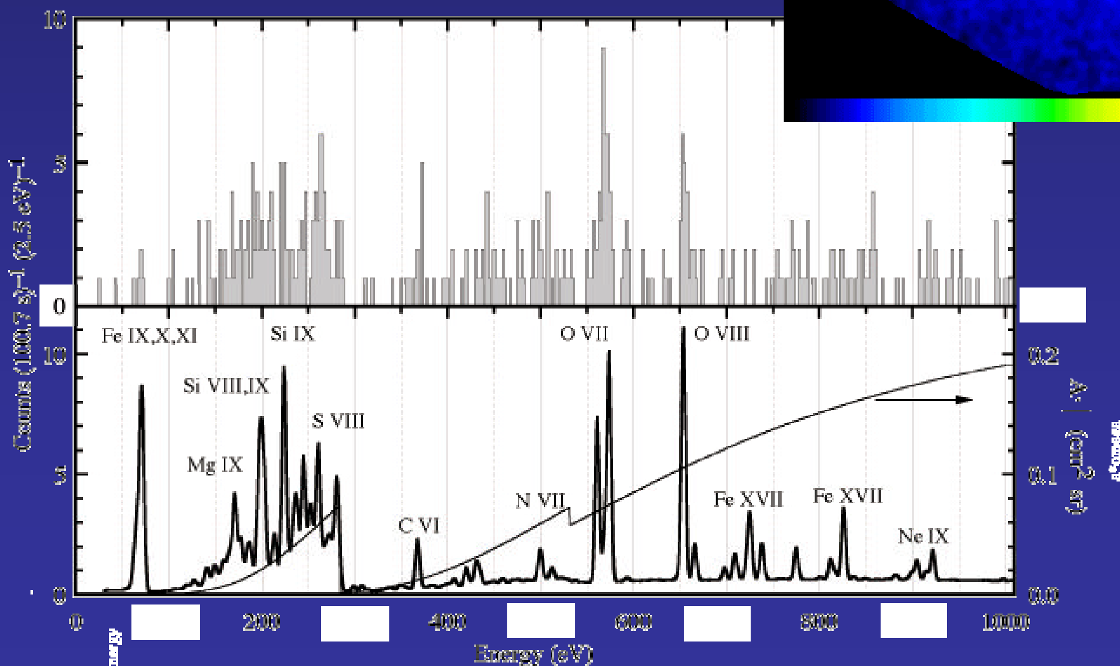
Desirements for CONX Observations of Cometary and Solar System CXE

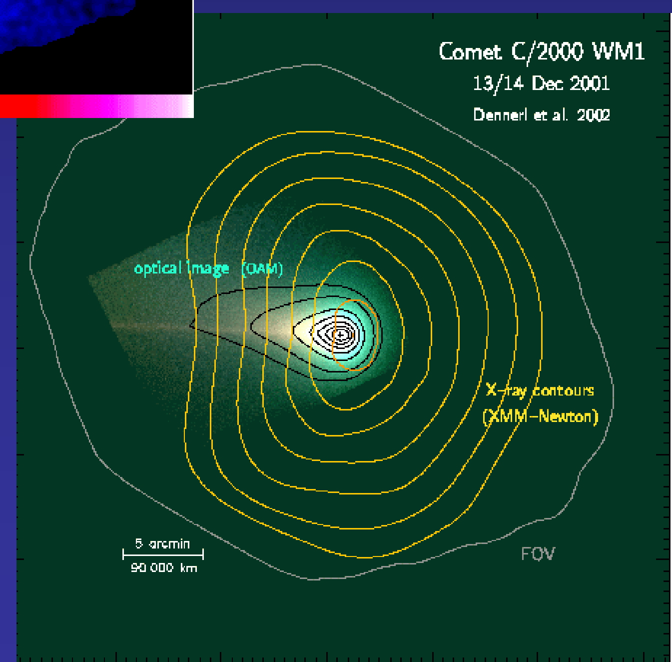
- 0.1 - 1.0 keV spectral imaging w/ SXT
  - 5 eV spectral resolution for extended sources
  - 1” spatial resolution, 8’ x 8’ FOV
  - >1000 cm^2 effective area
- Non-sidereal tracking, up to 1’/hr
- Low count rate diffuse measurement capability down to 10^{-3} cps
- Multi-day monitoring capability @ few hrs/day
- Contemporaneous optical monitoring

What we expect to see in a CONX comet observation







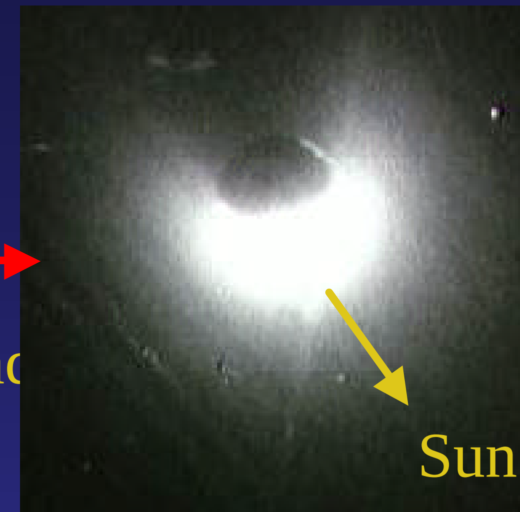


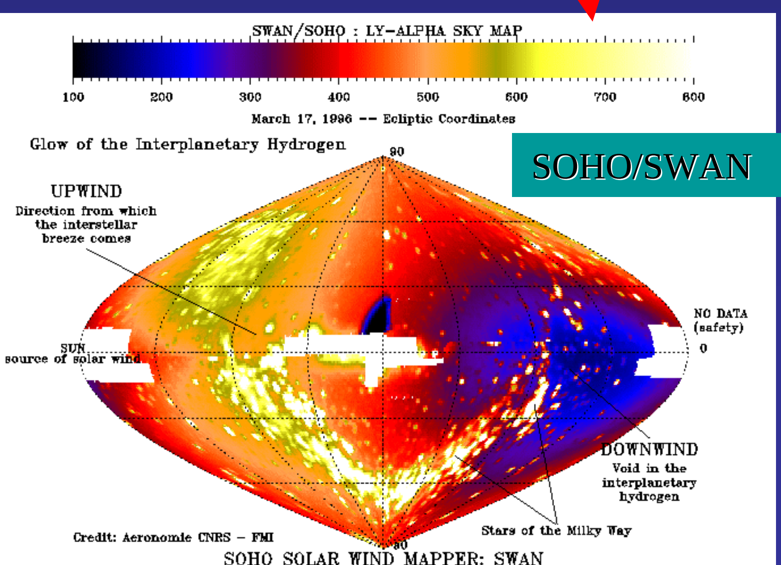
Non-Cometary Implications

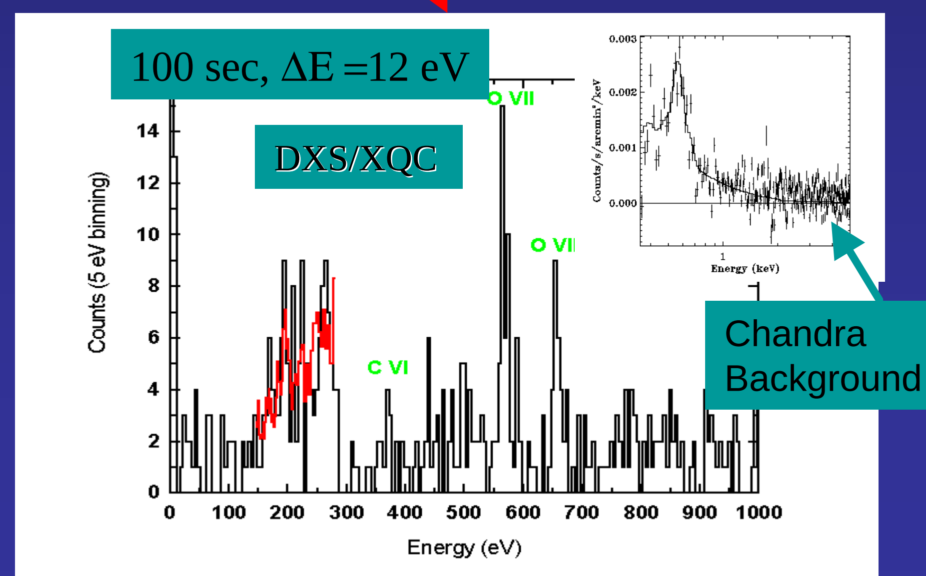
- X-ray emission from any Solar System extended atmosphere, but not solid surfaces

  => Planetary Atmospheres, Io torus, comets, ISM
- Geocoronal Lyman α, ? ? ? ? ? ? ? ? ? ? ? ? ?
- Important contributor to the Soft X-ray Background
- Heliosphere/heliopause imaging, Lyman α

  (Image stellar winds in other astrospheres?)







Evidence for Planetary CXE

Earth

•Atmosphere Explorer C 1974, Arecibo Incoherent Scatter Radar (Maher and Tinsley 1977) of electron and neutral H abundances

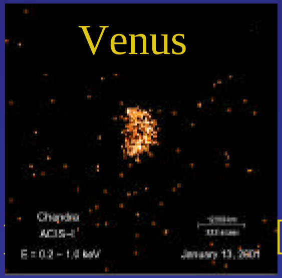
•CXE more important than Jeans escape for terrestrial H loss budget

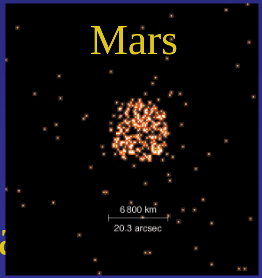
•IMAGE/LENA (Low Energy Neutral Atom) imager - response to quiescent solar behavior (Collier et al. 2001)

•IMAGE/HENA (High Energy Neutral Atom) imager - CME response (Brandt 2001)

•Detection of heavy neutral atoms in the Earth’s magnetosphere => Interaction of extended, cold H envelope of the Earth with SW via CXE

Venus & Mars





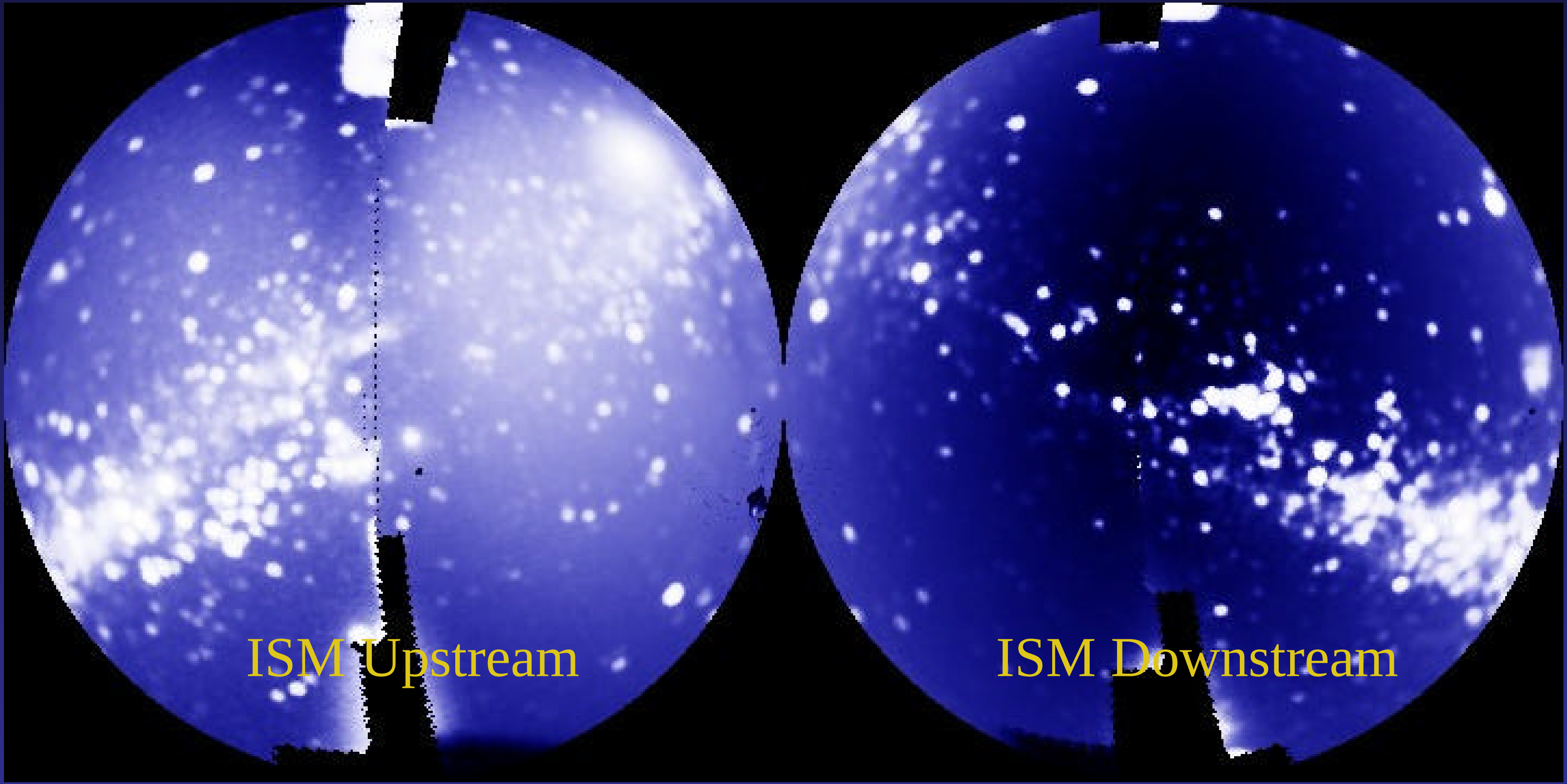
•Rusell et al. 1983 : CXE 10x more active at Venus than Mars

•Dennerl et al. 2002, Dennerl 2003 :CXE at Venus negligible,

Jupiter

•Sodium CXE in Io flux torus (Smyth and Combi 1991); X-ray emission from Io and Io flux torus (Elsner et al. 2002) ; Europa neutral atom torus (Mauk et al. 2003)

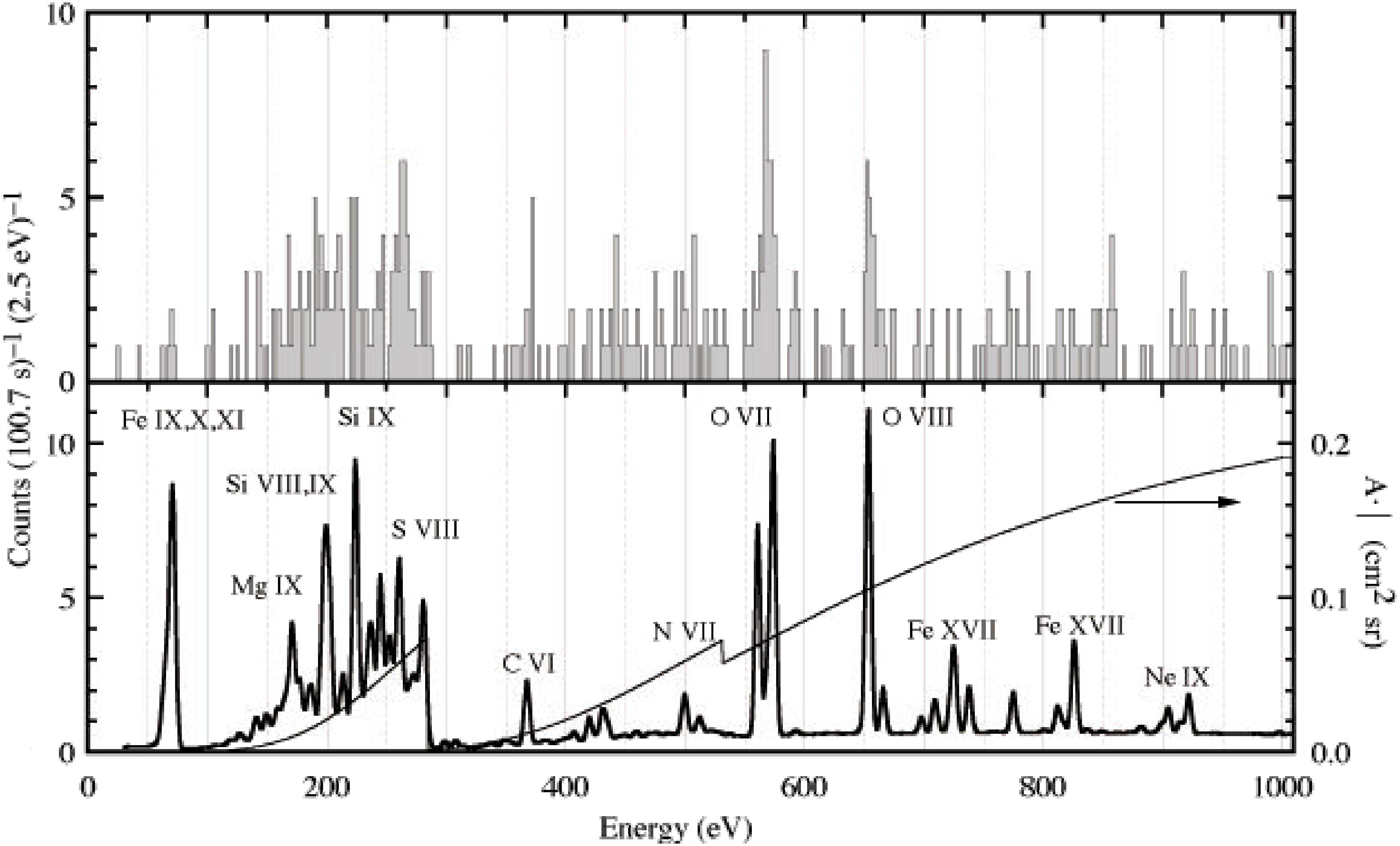
The Instreaming ISM & the SWAN All-sky Ly α



•"The ionization rate of interstellar H atoms by charge exchange with solar wind protons and solar EUV radiation is the main factor governing the H distribution in the solar system, and hence the Lyα emissivity distribution and Lyα emission pattern." - R Lallement et al., A&A 252, 385-401 (1991), from models of Voyager/UVS data

•IMAGE/LENA has detected ISM/SW upstream-downstream asymmetry in heavy neutrals - Collier et al 2001, Moore et al. 2002

Soft X-ray Background Calorimeter Spectrum

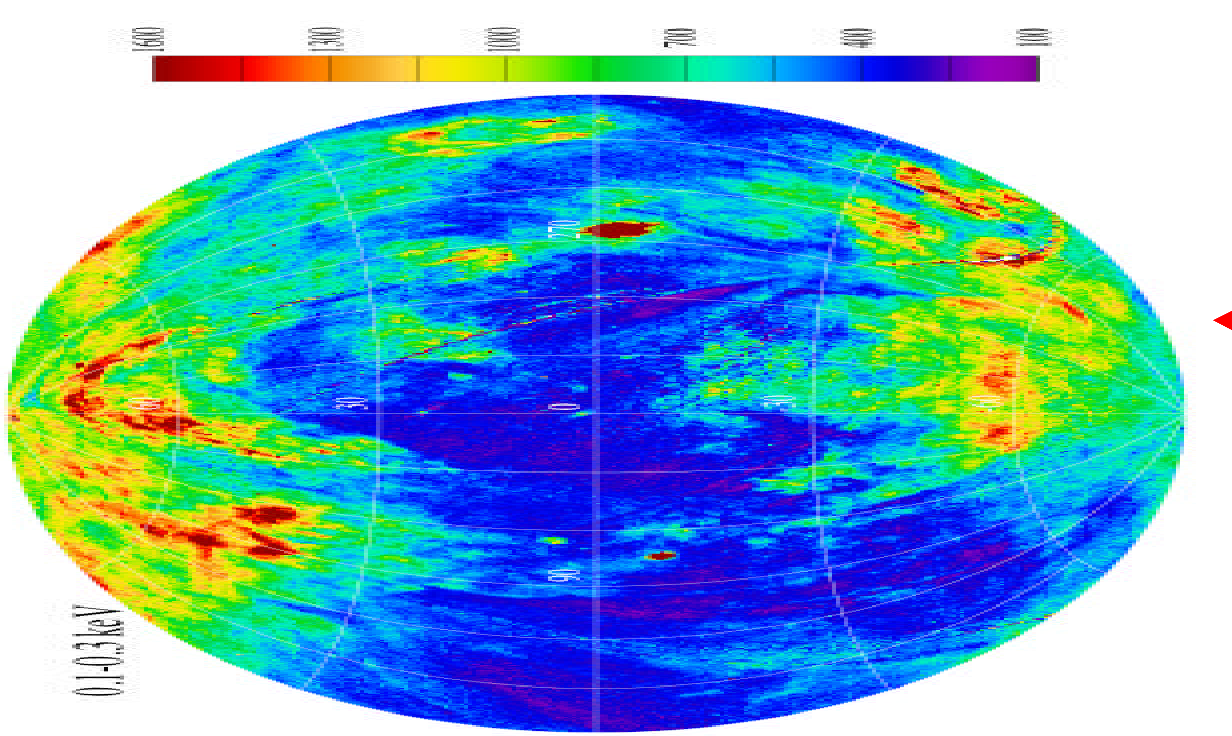


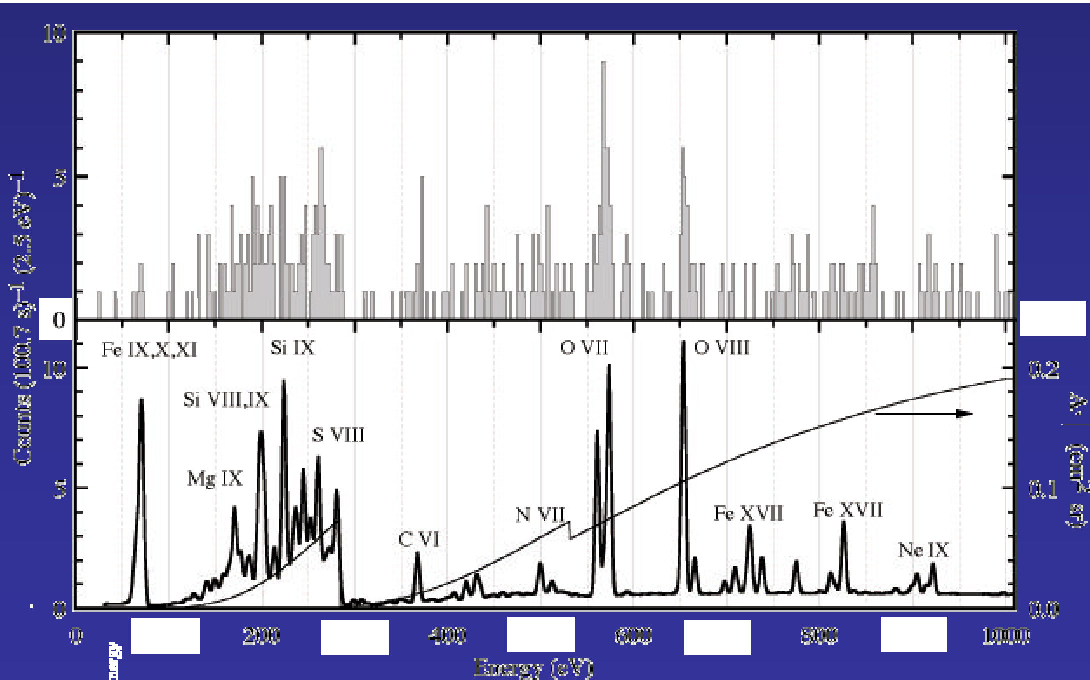
- Sounding rocket flight by McCammon et al. 2002
- 100 second integration of dark sky at ΔE =12 eV
- Line energies consistent with CXE cometary excitation
- We expect a similar CONX cometary spectrum

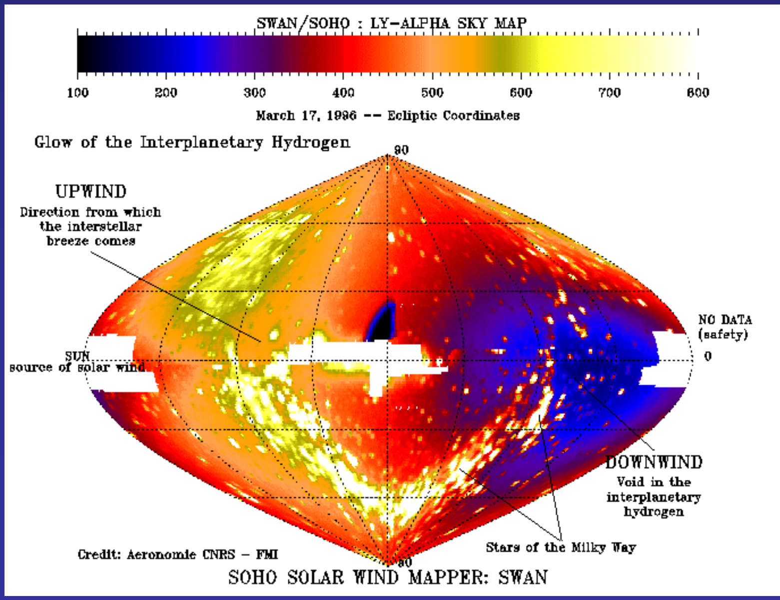
Desirements for CONX Observations of Astrosphere CXE

- 0.1 - 1.0 keV spectral imaging w/ SXT
  - 5 eV spectral resolution for extended sources
  - 5” spatial resolution, 1’x1’ FOV
  - >10,000 cm^2 effective area
- Sidereal tracking
- Low count rate diffuse measurement capability down to 10^{-3} cps

What we expect to see in a CONX soft xray background or astropshere observation







FINI!